REALM OF FLIGHT

U. S. DEPARTMENT OF COMMERCE

CHARLES SAWYER, *Secretary*

CIVIL AERONAUTICS ADMINISTRATION

CHARLES F. HORNE, *Administrator*

5.

REALM OF FLIGHT

Presenting Practical Information About Weather In Relation to the Piloting of Private Aircraft

By George Sidney Stanton
Consultant, Aviation Training Service,
Civil Aeronautics Administration

Revised June 1, 1951

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Price 60 cents.

each of which a radio transmitting device attached to a balloon ascends every 12 hours to altitudes as high as 10 miles, providing a complete record of temperature, pressure, and humidity at the higher levels.

Every 6 hours (at 1:30 and 7:30 a. m., and 1:30 and 7:30 p. m., Eastern Standard Time) this information, together with other data collected by radio, telephone, and telegraph, is assembled and plotted on weather maps. These maps provide specific information concerning the weather in all parts of the country, and provide the meteorologists with material from which they are able to make weather predictions.

Four times daily each airway forecast center issues forecasts especially designed to indicate flying conditions anticipated for the following *8 hours*—"regional forecasts" for the entire region, "route forecasts" for the individual airways, and "terminal forecasts" for all the important airway terminals.

This service is made available to pilots at airports and weather stations, as well as by radio broadcasts. In addition, a staff of trained meteorologists is on duty 24 hours a day at about 150 airways terminals to chart and analyze weather reports and to discuss weather conditions with pilots.

A further service to pilots is the "trip forecast," available upon request in person, by telephone, or by telegraph. This is issued for an individual flight, and predicts the weather likely to be encountered along the route. To take full advantage of this special service, the pilot must be specific in stating:

1. Type of plane.
2. Cruising speed.
3. Type of flight (whether contact or instrument).
4. Place and estimated time of departure.
5. Route to be taken.
6. Intermediate stops planned and their duration.
7. Destination and estimated time of arrival.

By the intelligent use of all these specific aids, coupled with a fundamental knowledge of weather characteristics, the pilot should be able to understand the present weather, be aware of changes likely to occur, and thus plan and make his flight with safety.

Figure 1. The troposphere and stratosphere form "The Realm of Flight."

II. The Nature of the Atmosphere

We live at the bottom of an ocean of air called the atmosphere. This ocean extends upward from the earth's surface for a great many miles, gradually becoming thinner as it nears the top. The exact upper limit has never been determined, but has been estimated to be anywhere from a few hundred miles to a few thousand miles. Near the surface the air is relatively warm owing to contact with the earth.[1] (The temperature in the United States averages about 59° F. the year round.) As altitude increases the temperature decreases by about $3\frac{1}{2}$° F. for every 1,000 feet,[2] until the air reaches a temperature of about 67° F. below zero at 7 miles above the earth. From that point upward, there apparently is no further temperature drop with increasing height.

The atmosphere is classified into two layers: the upper layer, where temperature remains practically constant, is known as the "stratosphere";[3] the lower layer, where the temperature changes, is known as the "troposphere."[4] (See fig. 1.) The private pilot has no occasion to go as high as the stratosphere, and anyway it is extremely uncomfortable up there; so his interest naturally centers in the lower layer—the troposphere. In this region all of our weather occurs and practically all of our flying is carried on. The top of the troposphere lies from 5 to 10 miles above the earth's surface.

[1] Heat reaches the earth in the form of short waves from the sun. These waves pass through the air without warming it appreciably. The surface of the earth absorbs this heat and returns it to the air principally by contact (conduction).

[2] This is known as the "normal lapse rate."

[3] "Strato" indicates a uniformity (lack of change).

[4] "Tropo" means changing.

Obviously a body of air as deep as the atmosphere has tremendous weight. It is hard to realize that the normal sea-level pressure upon our bodies is about 15 pounds per square inch, or a total of 20 tons upon the average man. The reason we don't collapse is that this pressure is equalized by an equal pressure within the body. In fact, if the pressure were suddenly released, the human body would explode like a toy balloon. As we fly upward in the atmosphere, we not only become colder (it is always freezing above 18,000 feet) but we also find that the air is thinner. At first we lose pressure rapidly and at 18,000 feet the pressure is only half as great as at sea level.

Oxygen and the Human Body

The atmosphere is composed of gases—about four-fifths nitrogen, and one-fifth oxygen, with approximately 1 percent of various other gases mixed in. Oxygen is essential to human life. At 18,000 feet altitude, with only half the normal atmospheric pressure, we would be breathing only half the normal amount of oxygen. Our reactions would be definitely below normal, and many of us would become unconscious. (In fact the average person's reactions become subnormal at 10,000 feet altitude.)

To overcome these unfavorable conditions at higher altitudes, pilots who are required to fly in this upper atmosphere use oxygen equipment to supply the deficiency and wear heavy clothes, often electrically heated; or they fly in sealed cabins in which the temperature, pressure, and oxygen content of the air can be maintained within proper range.

Figure 2. Barometric pressure at a weather station is expressed in terms of pressure at sea level.

III. Significance of Atmospheric Pressure

In the preceding chapter we mentioned that the average weight, or pressure of the atmosphere, is about 15 pounds per square inch at sea level. The actual pressure at a given place and time, however, is dependent upon several factors—the altitude, the temperature, and the density of the air column. These conditions very definitely affect flight.

For ordinary flights, the most noticeable effect of difference in pressure due to altitude becomes evident in take-offs and landings, in rate of climb, and in the higher speeds necessary to prevent stalling. An average small plane which requires a 1,000-foot run for take-off from La Guardia Field (at sea level) will require a run almost twice as long to take off at Denver, Colo., which is 5,000 feet above sea level.[5] The climb, too, is much slower and a greater distance is required to gain sufficient altitude to clear any obstructions. In landing, the difference is not so noticeable except that the plane has greater speed when it touches the ground. (See figs. 3 and 3a.)

Measurement of Atmospheric Pressure

It might be advisable at this point to find out how pressure is measured, recorded, and reported by the Weather Bureau. A barometer is generally used which measures the height of a column of mercury in a glass tube, sealed at one end and calibrated in inches. An increase in pressure forces the mercury higher in the tube; a decrease allows some of the mercury to drain out, thus reducing the height of the column. In this way, changes of pressure register in terms of inches of mercury. The standard sea-level pressure expressed in these terms is 29.92 inches at 59° F.

If all weather stations were located at sea level, the barometer readings, when entered on the weather map, would give a correct record of the distribution of atmospheric pressure at a common level. In order to achieve this result, each station translates its barometer reading into terms of sea-level pressure. A difference of 1,000 feet of elevation makes a difference of about 1 inch in the barometer reading. Thus, if a station located 5,000 feet above sea level found the mercury to be 25 inches high in the barometer tube, it would translate and report this reading as 30 inches $(25 + 5)$.[6] In this way, a uniform measurement can be established which, when entered upon the weather map, will show only the variations in pressure which are due to causes other than the altitude of the places where the measurements are taken. (See fig. 2.)

Since the rate of decrease in atmospheric pressure is fairly constant in the lower layers of the atmosphere, the approximate altitude can be determined by finding the difference between pressure at sea level and pressure at the given altitude. In fact this is the principle upon which the airplane altimeter operates. The scale on the altimeter, instead of indicating pressure in terms of inches of mercury, reads directly in terms of feet of altitude.[7]

[5] The purpose of the take-off run is to gain enough speed to secure lift from the passage of air over the wings. If the air is thin, more speed is required to obtain sufficient lift for take-off—hence, a longer ground run. It is also true that the engine is less efficient in thin air, and the thrust of the propeller is less effective.

[6] Actually the reduction of pressure to sea level is not so simple as given in this example.

[7] The altimeter uses a sealed vacuum cell instead of a mercury-barometer to register the differences in pressure. Altimeters are calibrated upon the assumption of standard sea-level pressure of 29.92 inches of mercury at 59° F. and an average decrease of pressure and temperature for each 1,000 feet of altitude. As suggested above, the altitude shown by the altimeter is only approximate. In addition, the altimeter is subject to installation errors, mechanical failure, and lag in recording true altitude. The chief cause of error lies in the extent to which pressure varies from the average. For this reason all altimeters embody some means of adjusting the dial so that the altimeter will indicate the elevation of the field from which the "altimeter setting" is received. (The zero reading may be set to show the ground level at a landing field, although this practice is not recommended except for beginning students.) The setting can be properly adjusted by using altimeter settings given in weather reports or, if the plane is on the ground, by turning the dial so that the needle points to the actual altitude of the landing field. The proper compensation for variation in temperature from the assumed average must be made by a computation which is of importance to pilots on instrument flight but of little significance for contact flight.

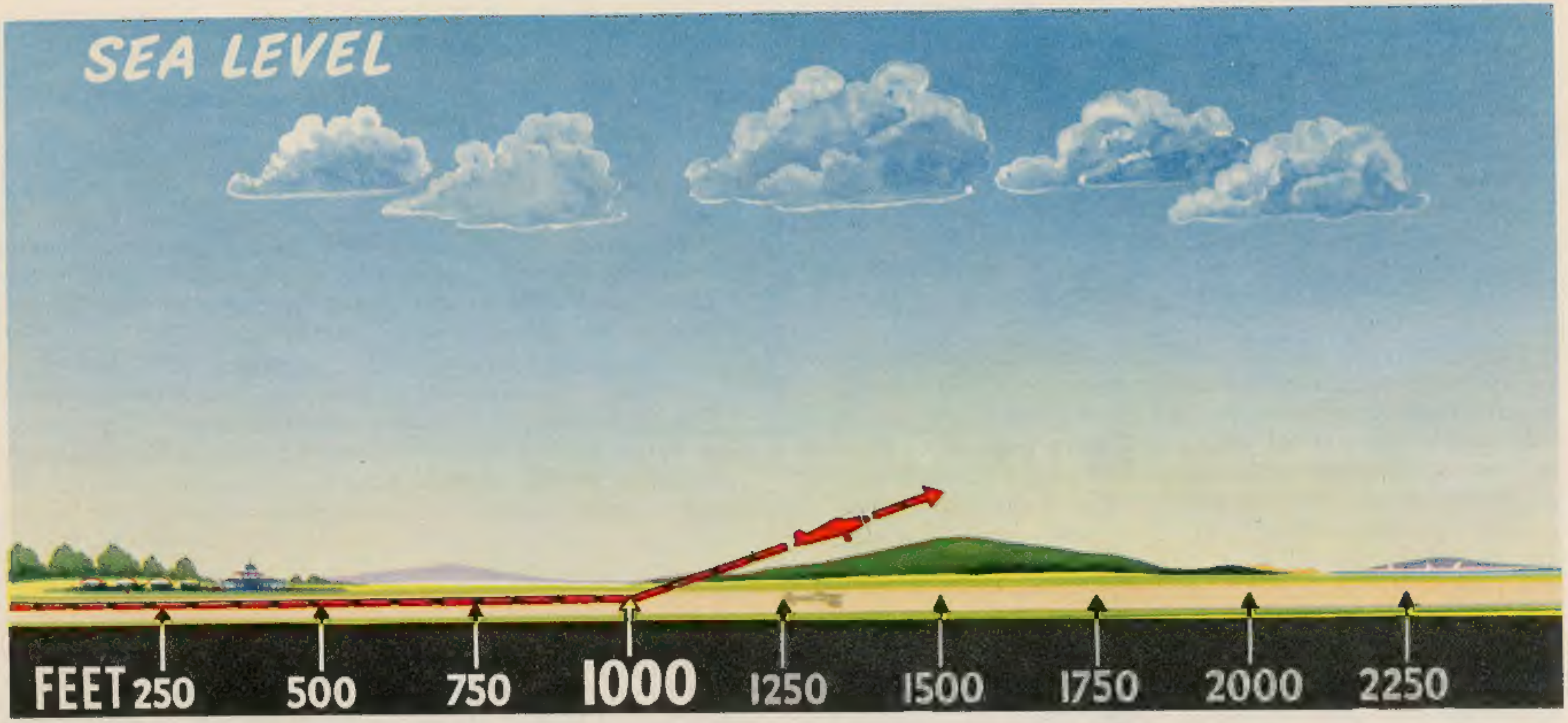


Figure 3. Atmospheric density at sea level enables a plane to take off in a relatively short distance.

Atmospheric pressure not only varies with altitude; it also varies with temperature. When air is heated it expands and has less density. If we fill a container to the brim with cold water and heat it to boiling point, we find that the water expands and some of it overflows. If we weigh the contents when cold, and again after heating, we find that the heated water weighs less. The same principle applies to air and, therefore, a cubic foot of warm air is less dense than a cubic foot of cold air. This difference in density, caused by temperature changes, affects flight in the same way as difference in density caused by elevation. For instance, at Denver on a cold day a small plane may take off with a 2,000-foot run, whereas on a hot day the air may be so thin that the plane is unable to leave the ground within the space of the available runway.

Effect of Differences in Density

Differences in density caused by changes in temperature cause changes in pressure which, in turn, create motion in the atmosphere, causing wind, clouds, and precipitation—in fact, all the phenomena which we roughly classify as "weather."

These items will be taken up in subsequent chapters. Meanwhile, we are now ready to look at a portion of the weather map called a "station model." (See fig. 4.)

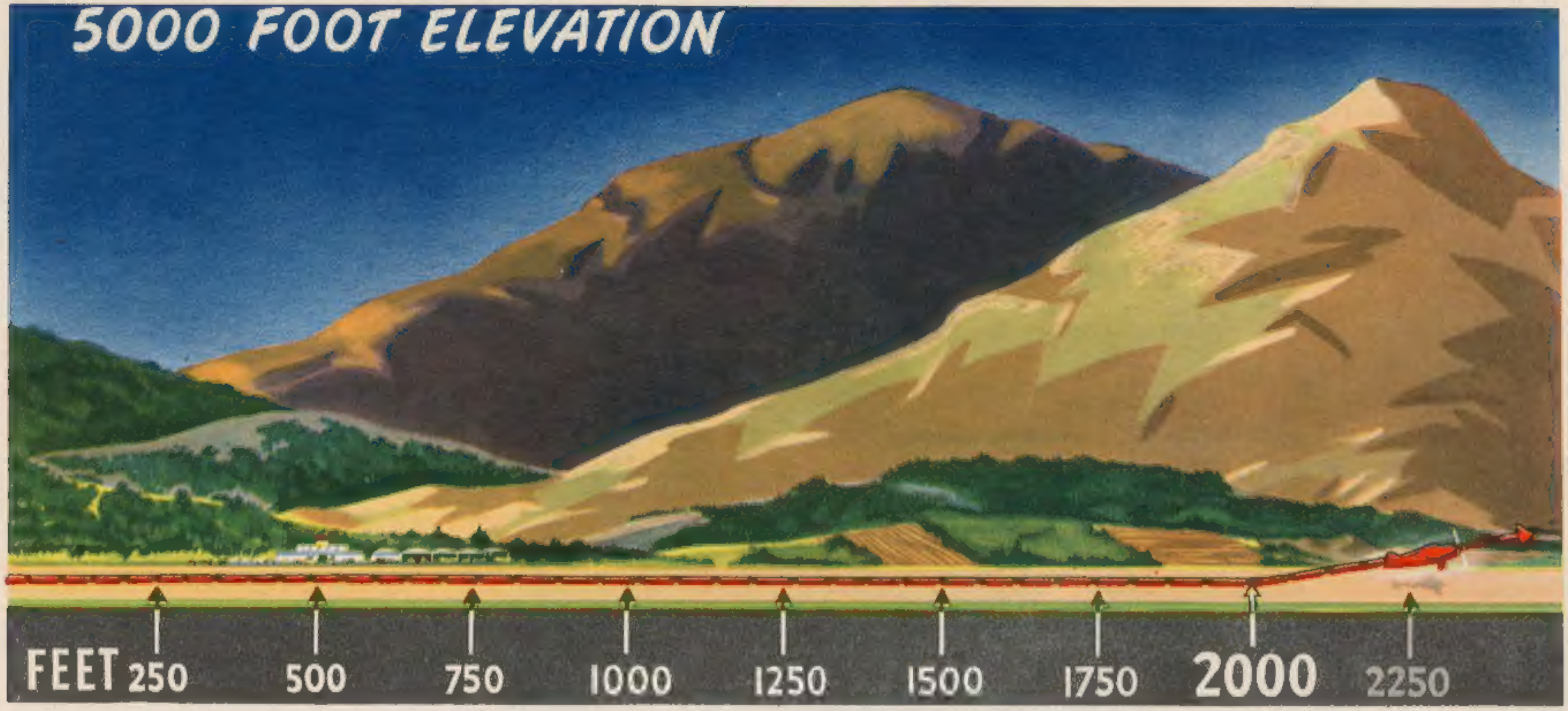


Figure 3a. The distance required for a take-off increases with the altitude of the field.

Here the meteorologist records the data received from weather stations, using an abbreviated form which the pilot can easily interpret. We shall disregard some of the items which are of little importance to the pilot; the others we shall discuss and learn to interpret in succeeding chapters.

At present we are interested in the pressure. The small circle represents the location of the station on the map. To the right, and slightly above, are three digits (203) indicating the pressure at the time of observation.

Pressure Recorded in "Millibars"

The mercury-barometer reading at the individual weather stations is converted to the equivalent sea-level pressure and then translated from terms of inches of mercury to a measure of pressure called millibars. One inch of mercury is equivalent to approximately 34 millibars; hence the normal atmospheric pressure at sea level (29.92), expressed in millibars, is 1013.2 or roughly 1,000 millibars. For economy of space the entry is shortened by omitting the initial 9 or 10 and the decimal point. The usual pressure readings range from 950.0 to 1040.0. On the station entry, a number beginning with 5 or higher presupposes an initial "9," whereas a number beginning with a 4 or lower presupposes an initial "10." For example: 653 = 965.3; 346 = 1034.6; 999 = 999.9; 001 = 1000.1, etc. The reading shown on the present station model is 203, which should be interpreted as 1020.3 millibars.

763814 O-47-2

Individually these pressure readings are of no particular value to the pilot; but when pressures at different stations are compared or when pressures at the same station show changes in successive readings, it is possible to determine many symptoms indicating the trend of weather conditions. In general, a marked fall indicates the approach of bad weather and a marked rise indicates a clearing of the weather.

The net amount of barometric change within the preceding 3 hours at each station is shown in tenths of millibars directly below the figures for atmospheric pressure. A plus or minus sign is used to show the direction of change. This number is followed by a symbol indicating special characteristics which are of no particular interest to the pilot.

On the present model the figure + 4 means that the barometer has risen a total of 4 tenths of a millibar, during the preceding 3 hours.

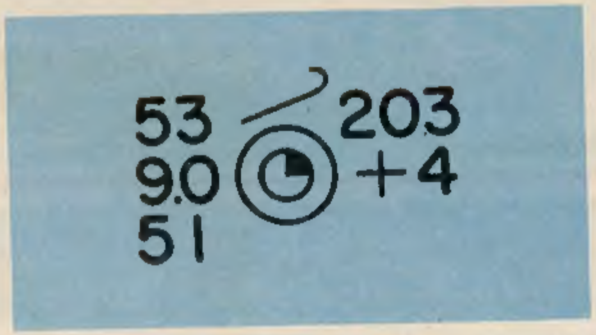


Figure 4. Station model showing method of recording atmospheric pressure by upper-right group of three digits. The numeral 203 indicates pressure of 1020.3 millibars. Change within preceding three hours is shown in tenths of millibars immediately below.

IV. Wind

The pressure and temperature changes discussed in the previous chapter produce two kinds of motion in the atmosphere—vertical movement of ascending and descending currents, and horizontal flow known as "wind." Both of these motions are of primary interest to the pilot because they affect the flight of aircraft in take-off, landing, climbing, speed, and direction; and they also bring about changes in weather, which may make a difference between safe flight and disaster.

The conditions of wind and weather occurring at any specific place and time are the result of the general circulation in the atmosphere, which will be discussed briefly in the following pages.

The atmosphere tends to maintain an equal pressure over the entire earth, just as the ocean tends to maintain a constant level. Whenever the equilibrium is disturbed, air begins to flow from areas of higher pressure to areas of lower pressure.

The Cause of Atmospheric Circulation

The factor which upsets the normal equilibrium is the uneven heating of the earth. At the equator the earth receives more heat than at areas to the north and south.[8] This heat is transferred to the atmosphere, warming the air and causing it to expand and rise. Thus, an area of low pressure is produced at the equator, and the heavier, cooler air from the north and south moves along the earth's surface toward the equator to equalize the pressure. This air in turn becomes warm and rises, thereby establishing a constant circulation which might consist of two circular paths, with air rising at the equator, traveling aloft toward the poles, and returning along the earth's surface to the equator, as shown in figure 5.

This theoretical pattern, however, is greatly modified by many forces, a very important one being the rotation of the earth. In the northern hemisphere this rotation causes air to flow to the right of its normal path. In the Southern Hemisphere air flows to the left of its normal path. For simplicity we shall confine our discussion to the motion of air in the Northern Hemisphere. (See fig. 6.)

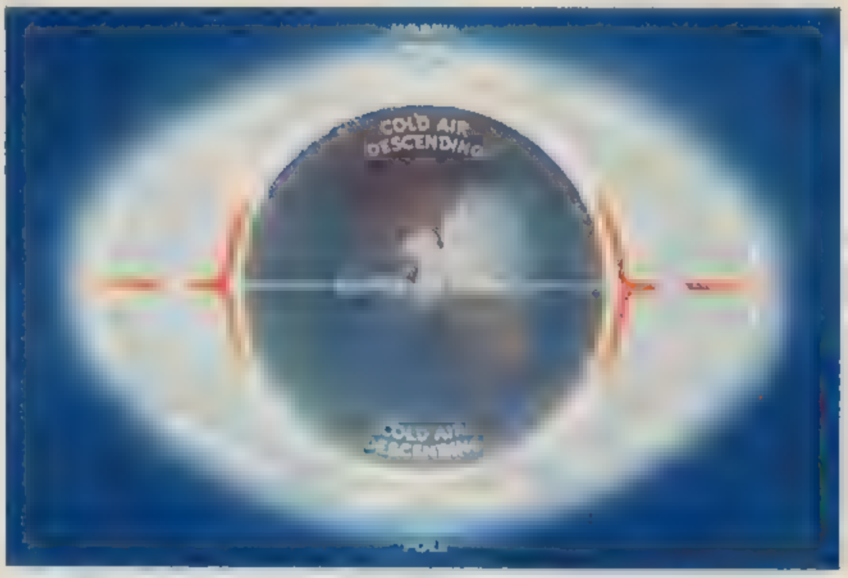


Figure 5. Heat at the equator would cause the air to circulate uniformly, as shown, if the earth did not rotate.

As the air rises and moves northward from the equator it is deflected toward the east and, by the time it has traveled about a third of the distance to the pole, it is no longer moving north-

[8] This is because the rays from the sun fall more directly upon the equator than upon other latitudes. Actually, the equator referred to here is the thermal equator rather than the geographical equator. As the axis of the earth tilts during its annual revolution around the sun, the thermal equator (the belt receiving vertical rays from the sun) ranges from Lat. 23½° South to Lat. 23½° North. This is the cause of our changes in season, with the accompanying changes in temperature, humidity, precipitation, etc.

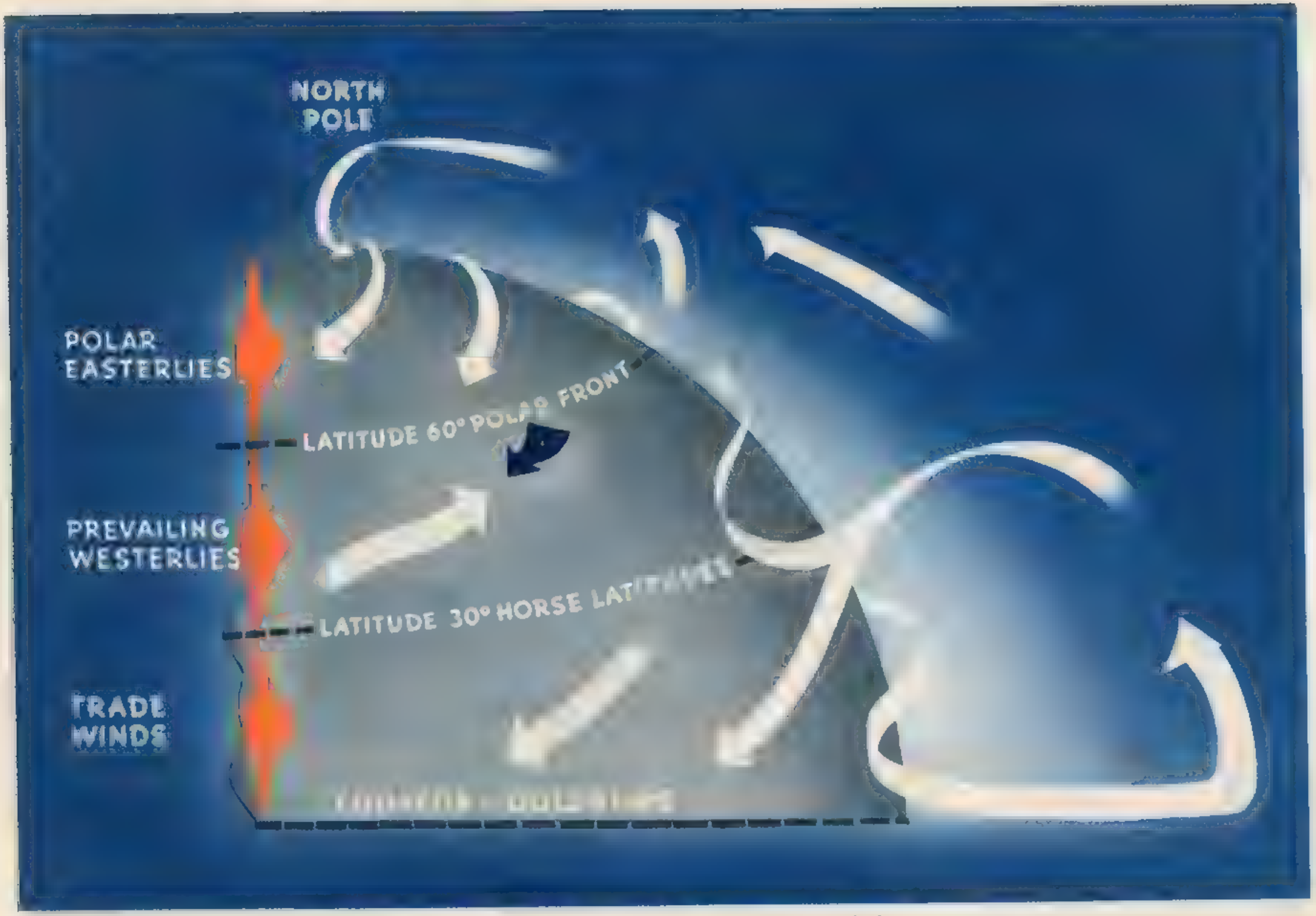


Figure 6. Principal air currents in the Northern Hemisphere.

Figure 7. Circulation of wind within a "low."

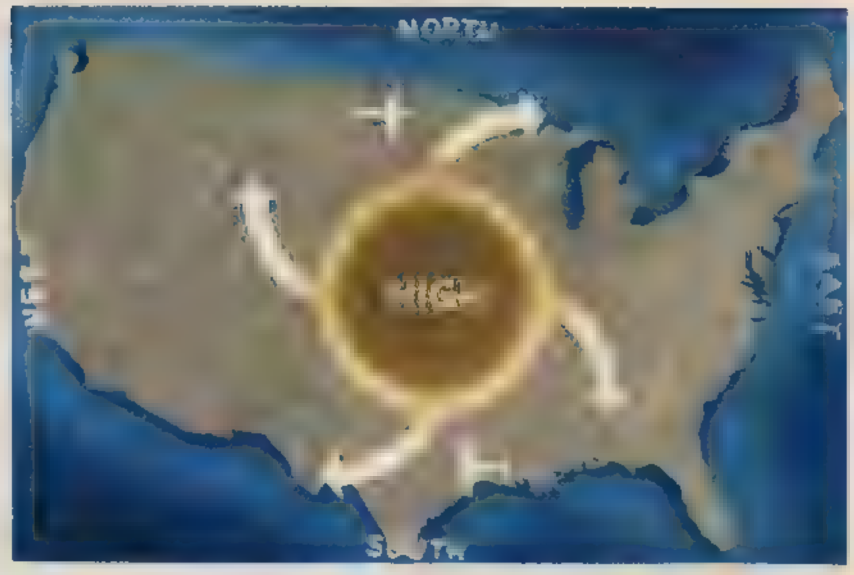


Figure 8. Use of favorable winds in flight.

ward, but eastward. This causes the air to accumulate in a belt at about latitude 30°, creating an area of high pressure.[9] Some of this air is then forced down to the earth's surface, where part flows southward, returning to the equator, and part flows northward along the surface.[10]

A portion of the air aloft continues its journey northward, being cooled en route, and finally settles down near the pole where it begins a return trip toward the equator. Before it has progressed very far southward it comes into conflict with the warmer surface air flowing northward from latitude 30°. The warmer air moves up over a wedge of the colder air, and continues northward, producing an accumulation of air in the upper latitudes.

The cold polar air is forced to break out spasmodically in waves which surge toward the equator, reducing the accumulated pressure and causing the rapid changes in weather so characteristic of the middle latitudes.

Further complications in the general circulation of the air are brought about by the irregular distribution of oceans and continents, the relative effectiveness of different surfaces in transferring heat to the atmosphere, the daily variation in temperature, the seasonal changes, and many other factors.

Regions of low pressure, called "lows," develop where air lies over land or water surfaces which are warmer than the surrounding areas. In India, for example, a low forms over the hot land during the summer months, but moves out over the warmer ocean when the land cools in winter. Lows of this type are semipermanent, however, and are of less significance to the pilot than the "migratory cyclones" or "cyclonic depressions" which form when unlike air masses come into contact.[11] These lows will be discussed in detail under "occlusions" in Chapter VII.

[9] In our latitudes a pilot making long eastward flights can nearly always climb to high altitudes and take advantage of favorable tailwinds. It is for this reason that the first trans-Atlantic flights were made from west to east.

[10] The air flowing southward is deflected toward the west, producing northeast winds, called "Trade Winds," in latitudes to the south of 30°. The air flowing northward is deflected toward the east, producing southwest winds, which become a part of the "Prevailing Westerlies," in latitudes to the north of 30°.

[11] The terms "cyclonic" and "cyclone" are generally used to indicate an area of low barometric pressure, together with its attendant system of winds, and should not be confused with tropical cyclones, tornadoes, or hurricanes, although some of their characteristics are fundamentally the same.

Figure 9. Convection currents form on shore winds in daytime.

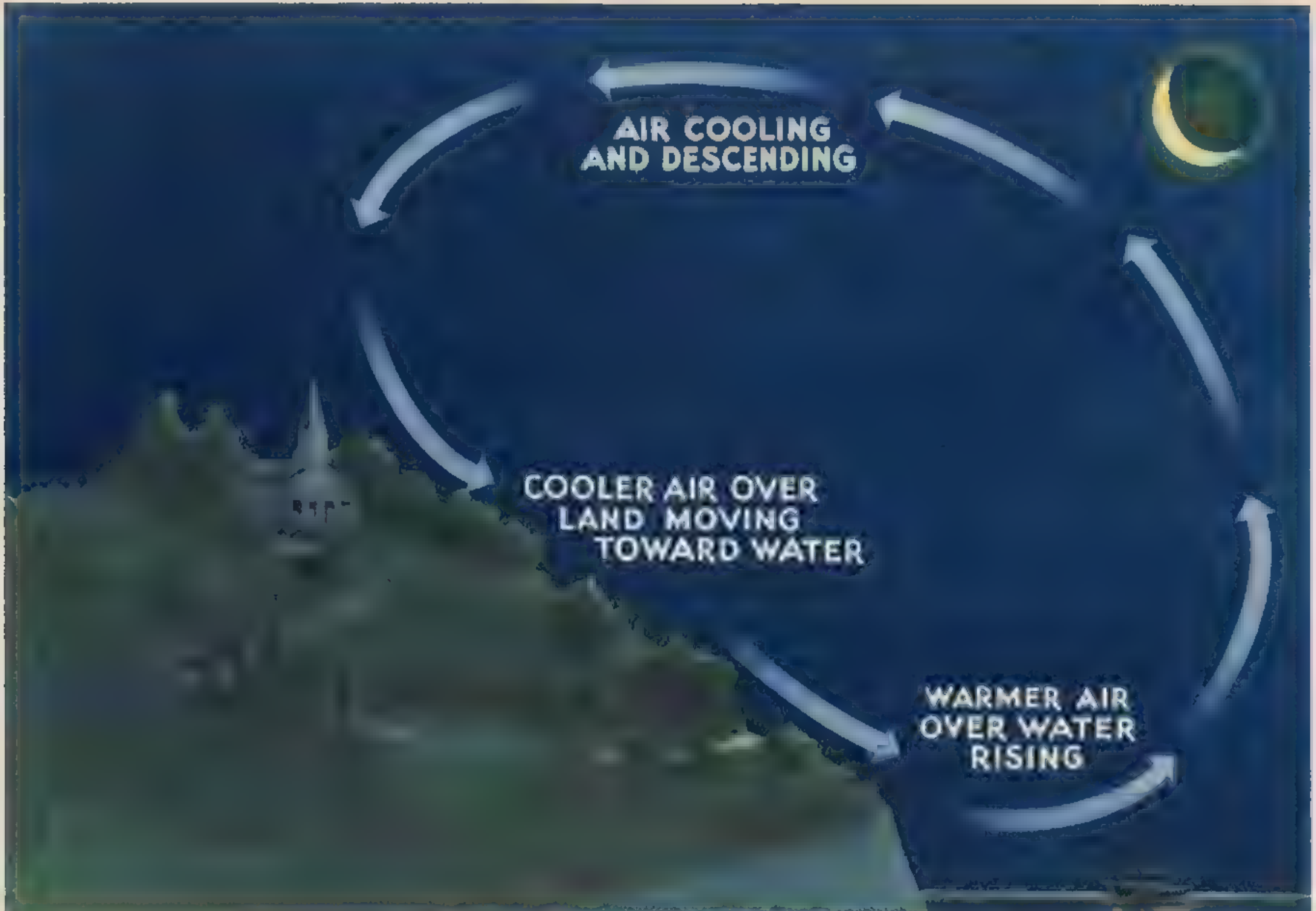


Figure 9a. Convection currents form off-shore winds at night.

At present we are concerned with the wind patterns associated with areas of high and low pressure. In the Northern Hemisphere wind is deflected to the right of its course. Air moving outward from a "high" flows in a clockwise spiral, and air moving toward a low flows in a counterclockwise spiral. A knowledge of these patterns frequently enables a pilot to plan his course to take advantage of favorable winds, particularly when making long flights. In flying from east to west, for example, he would find favorable winds to the south of a high, or to the north of a low.[12] (See figs. 7 and 8.)

We have now discussed the theory of general circulation in the atmosphere, and the wind patterns formed within areas of high pressure and low pressure. These concepts account for the large-scale movements of the wind, but do not take into consideration the effects of local conditions which frequently cause drastic modifications in wind direction and velocity close to the earth's surface.

Certain kinds of surfaces are more effective than others in heating the air directly above them. Ploughed ground, sand, rocks, and barren land give off a great deal of heat, whereas water and vegetation tend to absorb and retain heat. The uneven heating of the air causes small local circulations called "convection currents" which are similar to the general circulation just described.

This is particularly noticeable where land is adjacent to a body of water. During the day, the air over the land becomes heated and rises; the cooler air over the water moves in to replace it in

[12] This applies to conditions in the Northern Hemisphere; in the Southern Hemisphere the circulation is reversed.

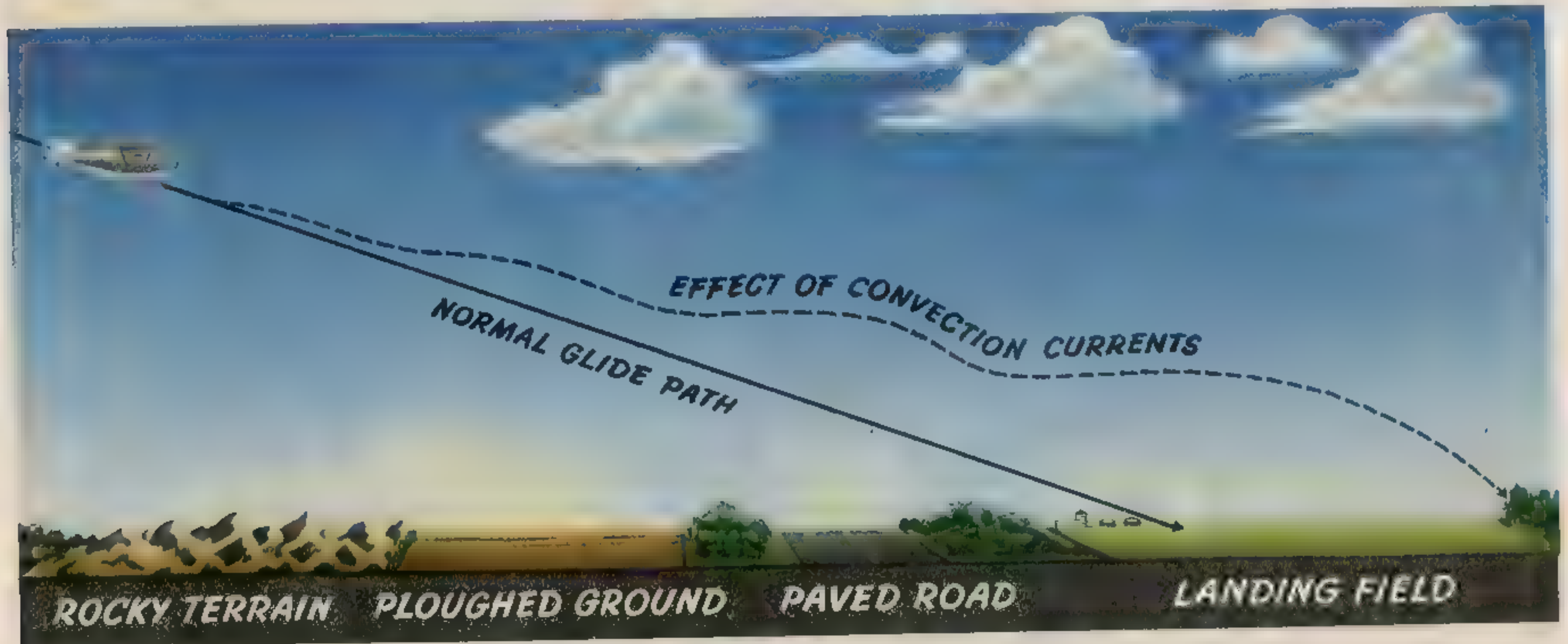


Figure 10. Varying surfaces affect the normal glide path. This illustration shows how some surfaces create rising currents which tend to make the pilot "over-shoot" the field.

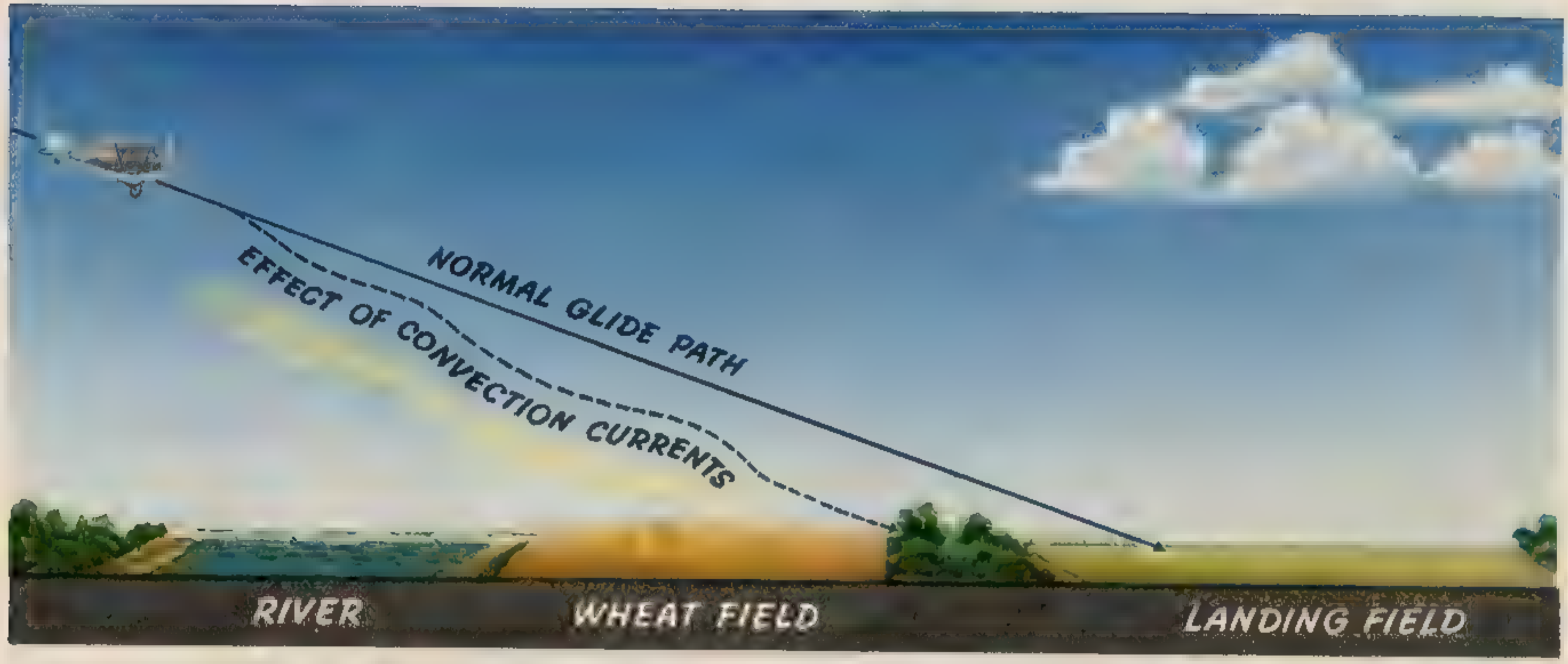


Figure 10a Descending currents prevail above some surfaces and tend to make the plane land short of the field.

the form of an on-shore wind. At night the land cools, and the water is relatively warmer. The cool air over the land, being heavier, then moves toward the water as an off-shore wind, lifting the warmer air and reversing the circulation. (See figs. 9 and 9a.)

Convection currents cause the bumpiness experienced by pilots flying at low altitudes in warm weather. On a low flight over varying surfaces, the pilot will encounter updrafts over pavement or barren places and downdrafts over vegetation or water. Ordinarily this can be avoided by flight at higher altitudes. When the larger convection currents form cumulus clouds, the pilot will invariably find smooth air above the cloud level. (See fig. 11.)

Convection currents also cause difficulty in making landings, since they affect the rate of descent. For example, a pilot making a constant glide frequently tends to land short or long of his spot, depending upon the presence and severity of convection currents. (See figs. 10 and 10a.)

These effects of local convection, however, are less dangerous than the turbulence caused when wind is forced to flow around or over obstructions. The only way for the pilot to avoid this invisible hazard is to be forewarned, and to know where to expect unusual conditions.

When the wind flows around an obstruction, it breaks into eddies—gusts with sudden changes in velocity and direction—which may be carried along some distance from the obstruction. An airplane flying through such turbulence is undependable and unsteady. If landing, it is likely to "drop in"; if taking off, it may fail to gain sufficient altitude for clearance of low objects in its path. Any landings or take-offs attempted under conditions of

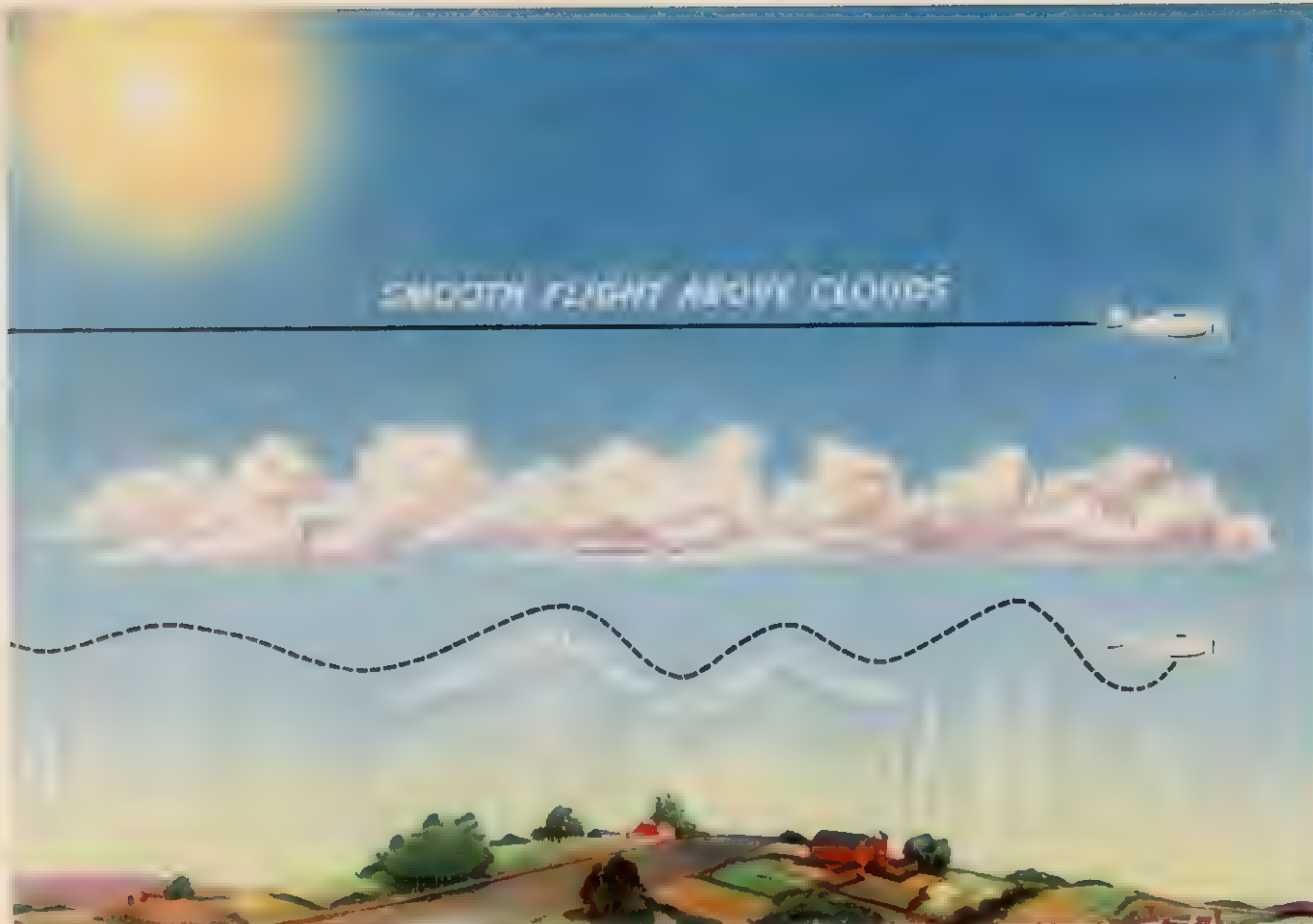


Figure 11. Avoiding turbulence caused by convection currents. This is done by flying above the cloud level.

gustiness should be made at higher speeds to maintain adequate control during the periods of low gust velocity. (See fig. 14.)

This same condition is noticeable to a greater extent where larger obstructions, such as bluffs or mountains, are involved. As shown in figure 13, the wind blowing up the slope on the windward side is relatively smooth and its upward current helps to carry the aircraft over the peak. The wind on the leeward side, following the contour of the terrain, flows definitely downward with considerable turbulence and tends to force the aircraft into the mountainside. The stronger the wind, the greater is the downward pressure and the accompanying turbulence. Consequently, in approaching a hill or mountain from the leeward side, a pilot should gain sufficient altitude well in advance. If there is any doubt of having adequate clearance, he should turn away at once and gain more altitude. Between hills or mountains, where there is a canyon or narrow valley, the wind will generally veer from its normal course and flow through the passage with increased velocity and turbulence. A pilot flying over such terrain needs to be alert for wind shifts, and particularly cautious if making a landing.

The weather map provides information concerning winds at the surface. The wind direction at each station is shown by an arrow. The arrowhead is represented by the station circle and points in the direction toward which the wind is blowing. Winds are given the name of the direction *from which* they blow.

Wind force is shown by "feathers" placed on the end of the

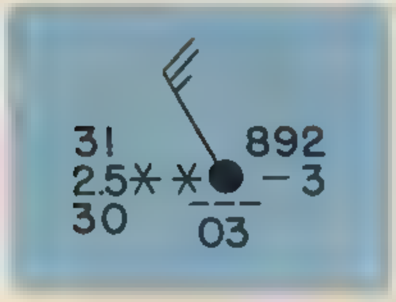


Figure 12. Station model showing method of indicating wind direction and velocity. The wind is shown to be from the northwest, with a velocity of 20 to 25 miles an hour.

arrow, the velocity being indicated by the number of half feathers or full feathers. Each half feather represents approximately 5 m. p. h. Thus, one full feather indicates wind velocity of 5 to 10

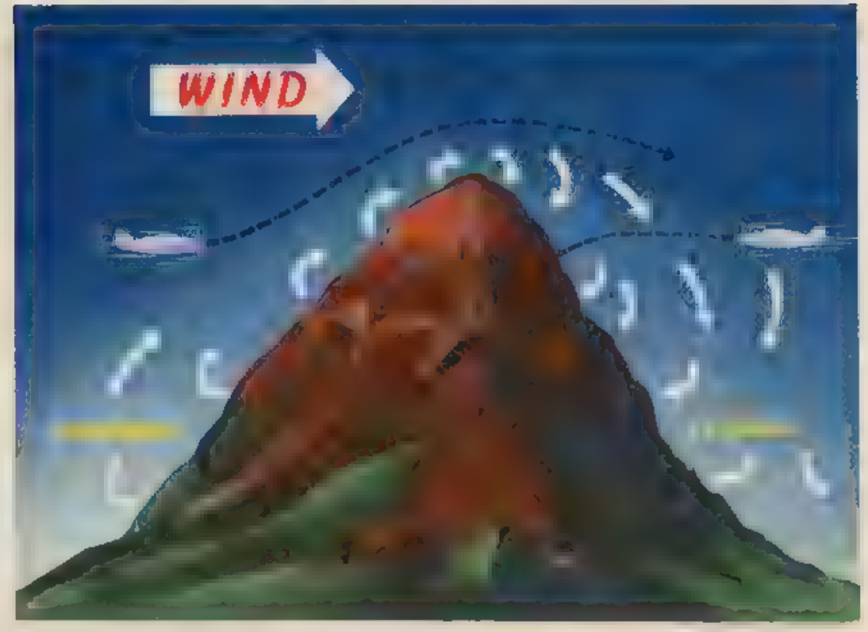


Figure 13. Planes approaching hills or mountains from windward are helped by rising currents. Those approaching from leeward encounter descending currents.

m. p. h.; 2½ feathers, wind velocity of 20 to 25 m. p. h., etc. The pilot can thus tell at a glance the wind conditions prevailing at any weather station. (See fig. 12.)

Observations of the winds at higher levels are made every 6 hours at about 200 stations; this information is available to pilots, upon request, at most weather stations.

The pressure at each station is recorded on the weather map and lines, called *isobars*,[18] are drawn to connect points of equal pressure. Many of the lines make complete circles to surround areas marked H (high) or L (low).

Isobars are quite similar to the contour lines appearing on aeronautical charts. However, instead of indicating altitude of terrain

[18] "iso" means equal, and "bar" means pressure. An isobar is drawn for each pressure interval of 3 millibars.

Figure 14. Turbulence caused by obstructions to normal flow of air.

and steepness of slopes, isobars indicate the amount of pressure and steepness of pressure gradients. If the gradient (slope) is steep, the isobars will be close together, and the wind will be strong. If the gradient is gradual, the isobars will be far apart, and the wind will be gentle. (See fig. 16.)

Isobars furnish valuable information concerning winds aloft. Close to the earth, wind direction is modified by the contours over which it passes, and wind velocity is reduced by friction with the surface. At levels two or three thousand feet above the surface, however, the direction is usually parallel to the isobars, and the velocity greater. Thus, while wind arrows on the weather map indicate winds near the surface, isobars indicate winds at slightly higher levels. In this manner the weather map usually provides the pilot with two choices of wind conditions from which he can select those most favorable for his flight. (See fig. 15.)

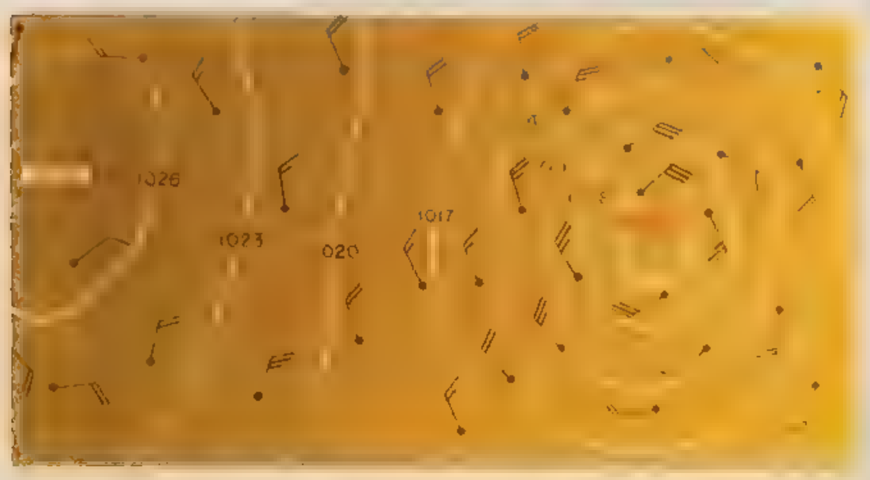


Figure 15. Velocity and direction of wind are shown on the weather map by "wind arrows" and isobars.

Even without a weather map the pilot can predict the winds aloft with reasonable accuracy. He generally will find that the wind at an altitude of 2,000 feet above the surface will veer about 45° to the right and will almost double in velocity. Thus, a north wind of 20 mph at the airport would be likely to change to a northeast wind of 40 m. p. h. at 2,000 feet.

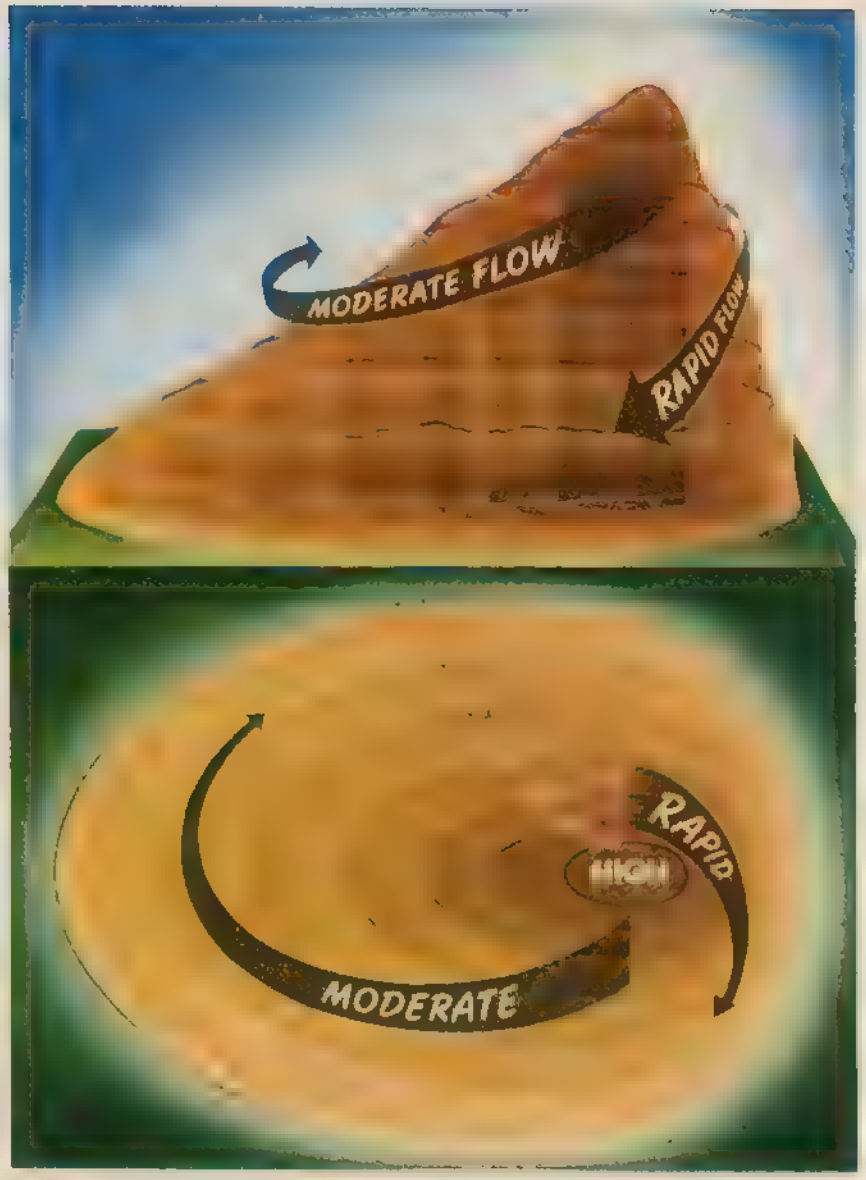


Figure 16. Above: pictorial representation of flow of air around a "high." Below: isobars on a weather map, indicate various degrees of pressure within a "high."

Figure 17. Cumulus clouds as they appear at low, intermediate, and high levels.

V. Moisture

The atmosphere always contains a certain amount of foreign matter—smoke, dust, salt particles, and particularly moisture in the form of invisible water vapor. The amount of moisture which can be present in the atmosphere depends upon the temperature of the air. For each increase of 20° F. the capacity is about doubled; conversely, for each decrease of 20° F. the capacity becomes only half as much as before.

We often speak of "the humidity," by which we mean the apparent dampness in the air. A similar term used by the Weather Bureau is "relative humidity," which expresses the percentage of moisture present as compared with the total capacity at the temperature given. For instance, "relative humidity 75 percent" means that the air contains three-fourths of its maximum capacity at the existing temperature.

For the pilot this relationship is expressed in a slightly different way: as "temperature and dew point." It is apparent from the foregoing discussion that if a mass of air at 80° F. has a relative humidity of 50 percent, and its temperature is reduced 20°, to 60° F., it will then be saturated (100 percent relative humidity). In this instance, the original relationship will be stated as "temperature 80—dew point 60." In other words, dew point is the temperature to which air must be cooled in order to become saturated.

Dew point is of tremendous significance to the pilot because it represents a critical condition of the air.

When temperature reaches the dew point, water vapor can no longer remain invisible, but is forced to condense, becoming visible on the ground as dew or frost, appearing in the air as fog or clouds, or falling to the earth as rain, snow, or hail.

It is interesting to note the various ways by which air can reach the saturation point. We have already shown how this is brought about by a lowering of temperature such as might occur under the following conditions: when warm air moves over a cold surface; when cold air mixes with warm air; when air is cooled during the night by contact with the cold ground; or when air is forced upward. Only the fourth method needs any special comment.

When air rises, it uses heat energy in expanding and pushing other air out of its path. Consequently, it loses heat rapidly. If the air is unsaturated, the loss will be approximately 5½ degrees F. for every 1,000 feet of altitude.

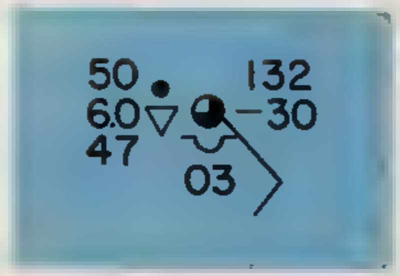


Figure 18. Station model showing method of indicating temperature and dew point. The temperature is shown to be 50° F., with the dew point indicated as 47° F.

Air can rise for three reasons: by becoming heated through contact with the earth's surface (convection currents as discussed in Chapter IV); by moving up a sloping terrain (as wind blowing up a mountainside); and by being forced to flow over another body of air (when air masses of different temperatures and densities meet. Under these conditions, the warmer, lighter, air tends to flow over the cooler, denser, air). This will be discussed in "Fronts," Chapter VII.

Air can also become saturated if it is subjected to precipitation.

Whatever the cause, the pilot knows that when temperature and dew point at the ground are close together he must be on the alert for low clouds and fog.

Temperature and dew point are indicated in degrees Fahrenheit on the station model, to the left of the center circle, with temperature above and dew point below. (See fig. 18.)

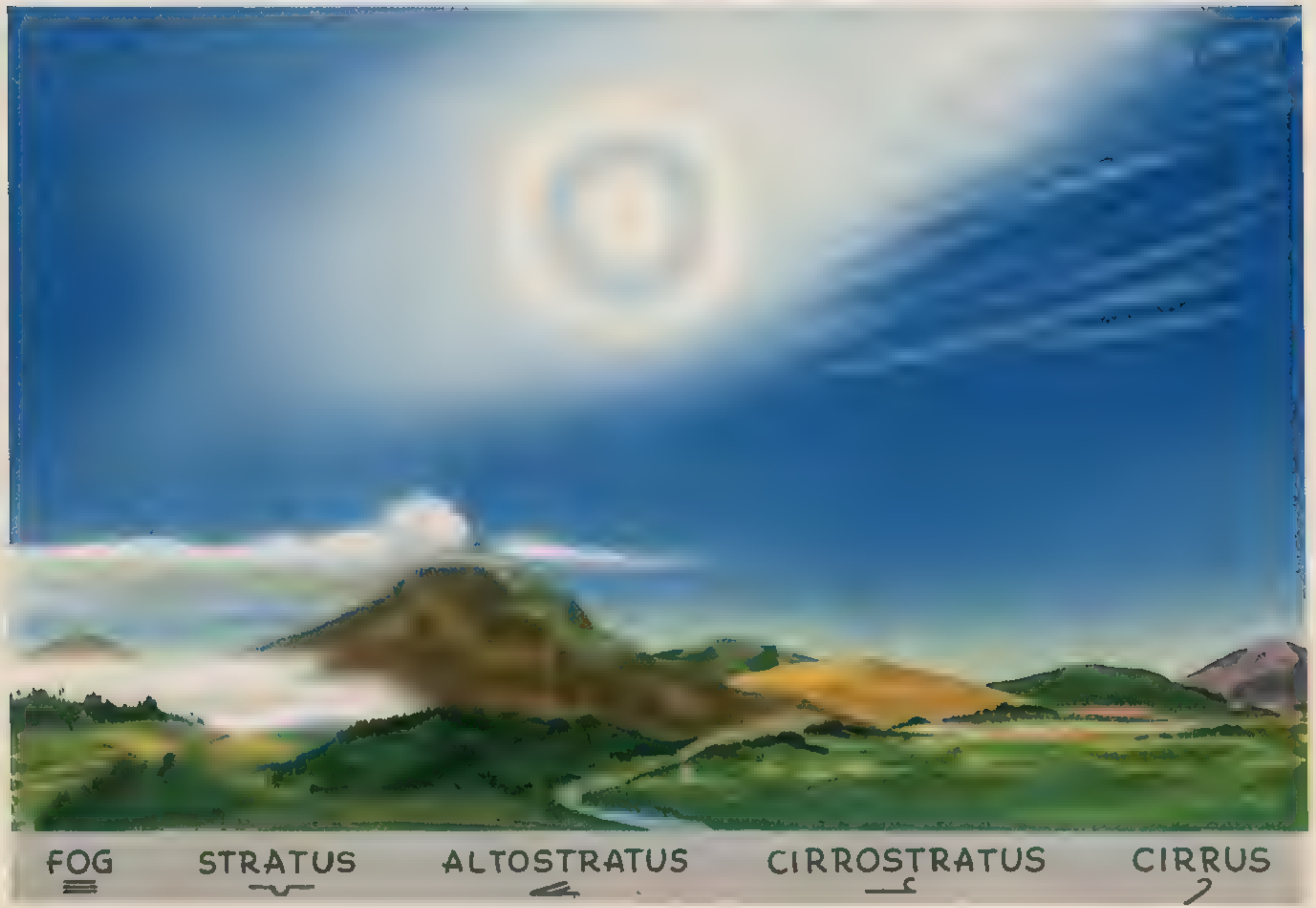


Figure 19. The appearance of stratus-type clouds at various altitudes.

VI. Results of Condensation

In the chapter on moisture it was shown that when temperature and dew point are close together the moisture in the air condenses and becomes visible in the form of fog or clouds, and that any further reduction in temperature will cause the moisture to be "squeezed out" in the form of precipitation—dew, frost, rain, snow, hail, etc.

The present chapter is concerned with a more detailed discussion of the forms of condensation. In connection with each, it is well to learn the basic symbols used by the Weather Bureau to indicate these conditions on the weather maps.

Dew and Frost

When the ground cools at night, the temperature of the air immediately adjacent to the ground is frequently lowered to the saturation point, causing condensation, which takes place directly upon objects on the ground in the form of water droplets (dew) if the temperature is above freezing; or ice crystals (frost) if below freezing.

Dew is of no importance to aircraft, but a frost deposit creates friction which interferes with the smooth flow of air over the wing surfaces to such an extent that it may prevent take-off. Therefore, it should always be wiped off before flight.

Fog

When the air near the ground is within a few degrees of the dew point, the water vapor condenses and becomes visible as a fine mist or cloud known as fog.[14] There are many types of fog, varying in degrees of intensity and classified according to the particular phenomena which caused them. One type, the "ground fog" which frequently forms at night in low places, is limited to a few feet in height, and is usually dissipated by the heat of the sun shortly after sunrise. Other types, however, can form at any time conditions are favorable to them. They extend to greater heights and may persist for days or even weeks. Along seacoasts fog often forms over the ocean and is blown inland. All fogs produce low visibilities and therefore constitute a serious hazard to aircraft.

[14] The formation of fog is also somewhat dependent upon the presence of "condensation nuclei"—dust, salt particles, and products of combustion near industrial regions. It is possible for fog to form when the relative humidity is only 80 percent (which might mean a spread of as much as 5 to 7 degrees between temperature and dew point).

Clouds

There are two fundamental types of clouds: those formed by vertical currents carrying moist air upward to its condensation point are lumpy or billowy in appearance and are called "cumulus," (fig. 17) which means an "accumulation" or a "pile"; those which develop horizontally and lie in sheets or formless layers like fog are called "stratus," (fig. 19) which means "spread out."

When clouds are near the earth's surface they are generally designated as "cumulus" or "stratus" unless they are producing precipitation, in which case the word "nimbo" (meaning "rain") is added—as "nimbostratus" or "cumulonimbus" (fig. 20).

If the clouds are ragged and broken, the word "fracto" (meaning "broken") is added—as "fractostratus" or "fractocumulus."

The word "alto" (meaning "high") is generally added to designate clouds at intermediate heights, usually appearing at levels of 5,000 to 20,000 feet—as "altostratus" or "altocumulus."

Clouds formed in the upper levels of the troposphere (commonly between 20,000 and 50,000 feet altitude) are composed of ice crystals and generally have a delicate, curly appearance, somewhat similar to frost on a window pane. For these clouds the word "cirro" (meaning "curly") is added—as "cirrocumulus" or "cirrostratus." At these high altitudes there is also a fibrous type of cloud appearing as curly wisps, bearing the single name "cirrus."

In Chapter VII the relationship will be shown between the

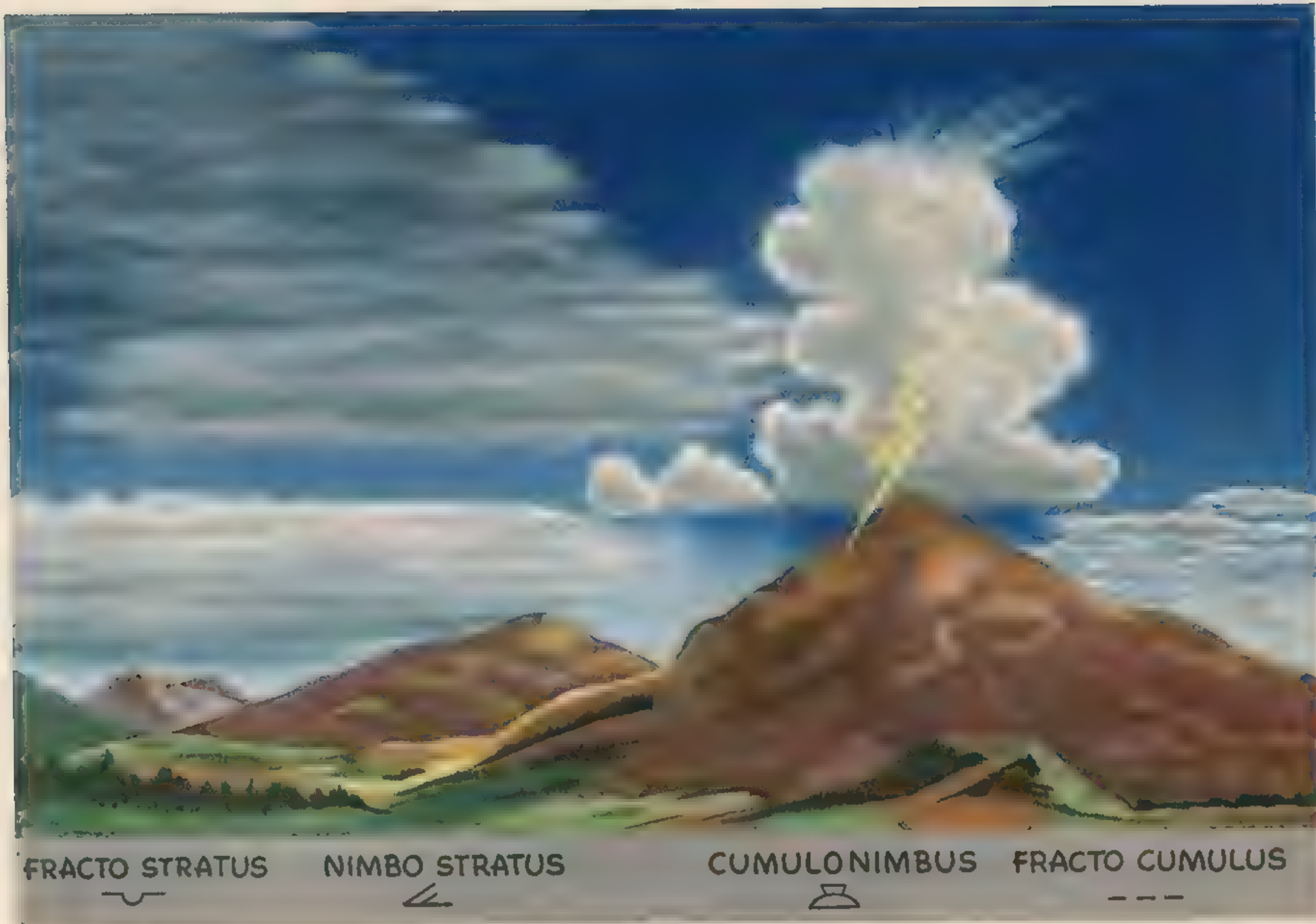


Figure 20. Various types of "bad weather" clouds.

various types of clouds and the kind of weather expected. At present we are chiefly concerned with the flying conditions directly associated with the different cloud formations.

The ice-crystal clouds (cirrus group) are well above ordinary flight levels, and do not concern the pilot except as indications of approaching changes in weather.

The clouds in the "alto" group are not normally encountered in flights of smaller airplanes, but they present a definite icing hazard to commercial or military planes. Altostratus clouds usually indicate the proximity of unfavorable flying weather.

The low clouds are of great importance to the pilot because they create low ceilings and low visibilities. They change rapidly, and frequently drop to the ground, forming a complete blanket over landmarks and landing fields. In temperatures near freezing they are a constant threat because of the probability of icing. Although Civil Air Regulations permit contact flight when these clouds are practically on the ground, the pilot should be constantly alert to any changes in conditions, and be prepared to land before his visibility is suddenly obscured.

Cumulus clouds vary in size from light "scud" or fluffy powder puffs to towering masses rising thousands of feet into the sky. Usually they are somewhat scattered, and the pilot can fly around them without difficulty. Under some conditions, however, particularly in the late afternoon, they are likely to multiply, flatten out, and close in. That leaves the pilot no alternative but to fly through a narrow tunnel in search of a landing field in the hope that he may reach safety before squalls and violent precipitation develop.

Cumulonimbus clouds (thunderheads) are very dangerous. When they appear individually or in small groups, they are usually of the type called "air-mass thunderstorms" (caused by heating of the air at the earth's surface) or "orographical thunderstorms" (caused by the upslope motion of air in mountainous regions). On the other hand, when these clouds take the form of a solid bank they are usually caused by a "front," in which case they are called "frontal thunderstorms."

Since the cumulonimbus clouds are formed by rising air currents, they are extremely turbulent; moreover, there is a possibility that an airplane flying in close proximity may be sucked into the cloud. Once inside, it will be subjected to up-currents and down-currents attaining velocities as great as 200 miles per hour. Airplanes have been known to be torn apart by the violence of these currents. In addition, the clouds frequently contain large hailstones capable of inflicting severe damage upon aircraft, lightning, and great quantities of water at temperatures conducive to heavy icing. Many "unexplained" crashes have probably been caused by the disabling effect of cumulonimbus clouds upon airplanes which have been inadvertently or intentionally flown into them. The only practical procedure for a pilot caught within a thunderstorm is to reduce airspeed so as to lessen the strain upon the structure of the aircraft, just as slow driving over rough roads lessens the strain upon an automobile. A safe speed for any airplane flying through turbulence is an indicated airspeed approximately double the stalling speed, and in no case greater than the normal cruising speed.

Figure 21 shows the important characteristics of a typical cumulonimbus cloud. The top of the cloud flattens into an anvil shape, which points in the direction the cloud is moving, generally with the prevailing wind. Near the base, however, the winds blow directly toward the cloud and increase in velocity, becoming violent updrafts as they reach the low rolls at the forward edge.

Within the cloud and directly beneath it are updrafts and downdrafts; in the rear portion is a strong downdraft which becomes a wind blowing away from the cloud.

The cloud itself is a storm-making factory. The updrafts lift the moist air quickly to its saturation point, whereupon it condenses and rain drops begin to fall. Before these have reached the bottom of the cloud, updrafts pick them up and carry them aloft, where they freeze and again start downward, only to repeat the process many times until they have become sufficiently heavy to break through the updrafts and reach the ground as hail or very large rain drops. As the storm develops, more and more drops fall through the turbulence, until the rain becomes fairly steady. The lightning which accompanies such a storm is probably due to the breaking up of the rain drops, producing static electricity which

Figure 21. "Cross section" of a cumulonimbus cloud (thunderhead).

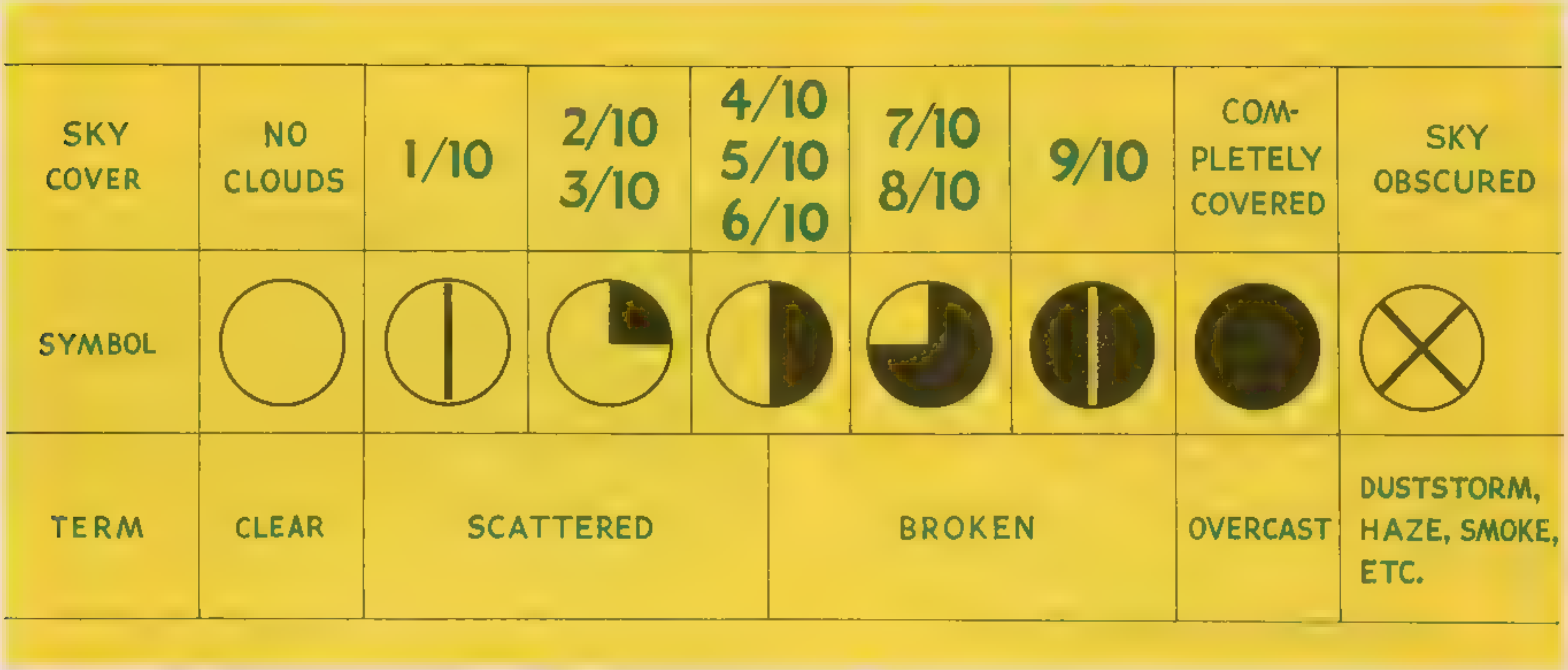


Figure 22. Weather-map symbols used to indicate "sky cover."

discharges spasmodically as lightning. The lightning causes a sudden expansion of the air in its path, which produces thunder.

It is impossible for a small plane to fly over these clouds (they frequently extend to altitudes of 35,000 feet). Usually they are too low to fly under. When they are close together the clear space between them is an area of violent turbulence. If the clouds are isolated, indicating local thunderstorms, it usually is possible to fly around them; but they should be given a wide berth, since they travel rapidly. If, however, they are "frontal" storms, they may extend for hundreds of miles, and the only safe procedure is to land immediately and wait until the cumulonimbus cloud formation has passed over.

The proportion of sky covered by clouds (sky cover) is shown on the weather map by the extent to which the station circle is filled in. (See fig. 22.)

Ceiling

When clouds lying below the 10,000-foot level cover more than half the sky, the height is reported as "ceiling" in terms of hundreds of feet. When clouds are above 10,000 feet, or when those below 10,000 feet do not cover half the sky, the ceiling is reported as "unlimited." On weather maps a figure is entered directly below the station circle, indicating ceiling in terms of hundreds of feet. Thus, "60" would indicate a ceiling of 6,000 feet. If the ceiling is unlimited, the figure may be omitted.

Figure 23. Basic "weather symbols" used on weather maps.

Visibility

Closely related to ceiling and cloud cover is "visibility"—the greatest horizontal distance at which prominent objects can be distinguished with the naked eye. On weather maps visibility is recorded at the left of the station circle by figures representing miles and tenths of miles. When visibility is 10 miles or more, it is considered unlimited, and the figures may be omitted from the map.

Precipitation

The various forms of precipitation do not require lengthy discussion. Aside from possible damage by hail and the danger of icing, precipitation offers no hazard to aircraft in flight, except that it is usually accompanied by low ceilings and visibilities that may suddenly be reduced to zero.

It is, of course, obvious that aircraft which may have accumulated snow while on the ground should never be flown until all

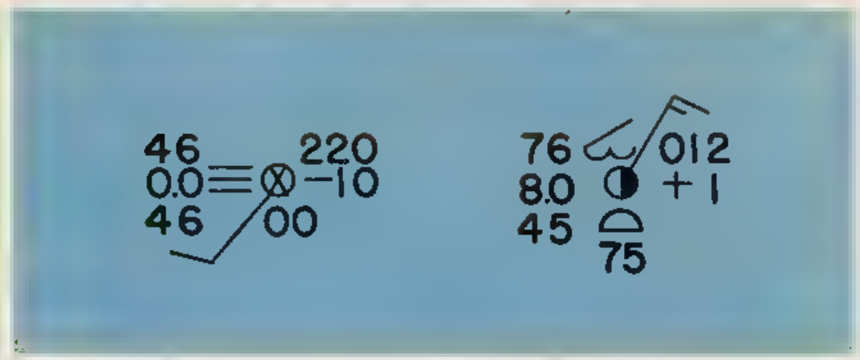


Figure 24. Typical recordings of weather reports on station models.

traces of snow have been removed, including the hard crust that frequently adheres to the surfaces. An aircraft which has been exposed to rain followed by freezing temperatures should be carefully checked before take-off to ascertain that the controls operate freely.

Although more than 100 symbols are used on weather maps to indicate "state of weather," the pilot need learn only the basic symbols given in figure 23. (The complete key is posted at weather stations.)

These symbols may be used in combination, e. g., $\underset{\bullet}{\equiv}$ rain and fog, or $\overset{\bullet}{*}$ rain and snow mixed; or may be multiplied to indicate greater intensity, e. g., $\bullet\bullet$ means continuous light rain; $\overset{\bullet}{\bullet\,\bullet}$ means continuous moderate rain; $\overset{\bullet}{\underset{\bullet}{\bullet\,\bullet}}$ continuous heavy rain. A bracket ( ]) indicates that the weather represented has occurred within the last hour, but not at the time of observation.

On the weather map, areas of precipitation are shown by green or gray shading.

VII. Air Masses and Fronts

The various air masses assimilate the temperature and moisture characteristics of the areas in which they originate—the coldness of polar regions, the heat of the tropics, the moisture of oceans, the dryness of continents.

As they move away from their source regions and pass over land and sea surfaces, the air masses are constantly being modified through heating or cooling from below, lifting or subsiding, absorption or loss of moisture. In general, however, they retain some of their original characteristics and can be recognized and identified.

The source of an air mass is indicated on weather maps by use of the following symbols:

A = arctic	m = maritime (formed over oceans).
P = polar	
T = tropical	c = continental (formed over land).

Two additional symbols (k — cold, w — warm) are based upon temperature. However, the actual temperature of the mass is less important than its temperature in relation to the land or water surface over which it is passing, and its temperature classification is, therefore, based upon this relationship. For example, an air mass moving from the polar regions usually will be colder than the land and sea areas over which it passes. It will, therefore, be classified as cold (k). On the other hand, an air mass moving from the Gulf of Mexico in winter usually will be warmer than the territory over which it passes and will, therefore, be classified as warm (w).[15] As an air mass moves from one surface to another, its temperature classification may be changed to indicate whether it is warmer or colder than the surface below. A Polar air mass, originally classified as cold (cPk), might prove to be warmer than the ground in the Rocky Mountains over which it passes. Consequently, it would be reclassified as warm (cPw).

If the air is colder than the surface (k), it will be warmed from below and convection currents will be set up, causing turbulence. Dust, smoke, and atmospheric pollution near the ground will be carried upward by these currents and dissipated at high levels, resulting in improved visibility. Such air is called "unstable."

Conversely, if the air is warmer than the surface (w), there is no tendency for convection currents to form, and the air is smooth. Smoke, dust, etc., are concentrated in lower levels with resulting poor visibility. Such air is called "stable."

From the combination of the source characteristics and the temperature relationship just described, we can predict with a fair degree of accuracy the flying conditions likely to be found within a given air mass.

Characteristics of a Cold Air Mass

Type of clouds	cumulus and cumulonimbus
Ceilings	generally unlimited (except during precipitation)
Visibilities	excellent (except during precipitation)
Unstable air	pronounced turbulence in lower levels (because of convection currents)
Type of precipitation	Occasional local thunderstorms or showers —hail, sleet, snow flurries

Characteristics of a Warm Air Mass

Type of clouds	stratus stratocumulus (fog, haze)
Ceilings	generally low
Visibilities	poor (smoke and dust held in lower levels)
Stable air	smooth, with little or no turbulence
Type of precipitation	drizzle

[15] In the summer Gulf air masses are colder than the areas over which they pass.

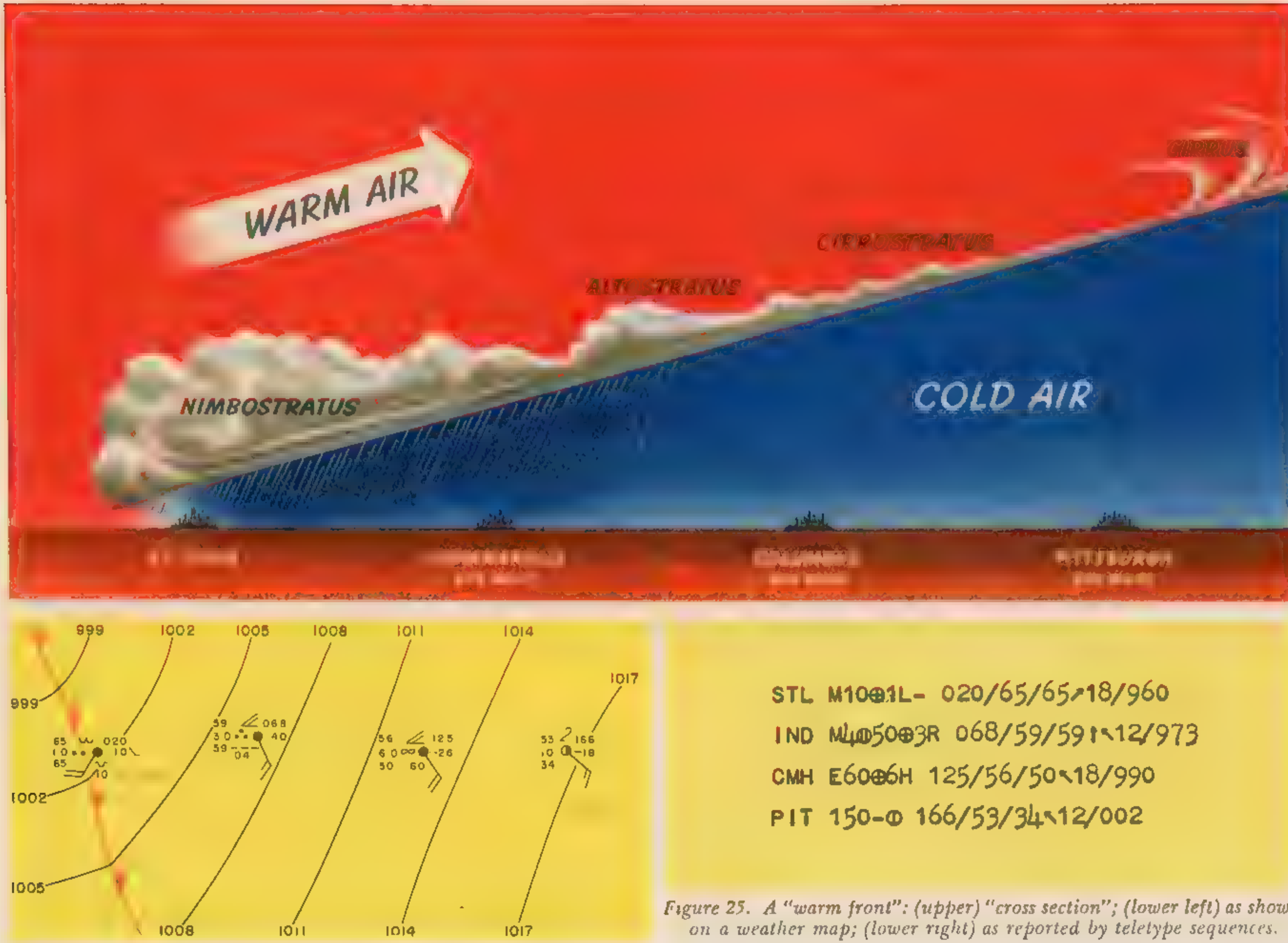
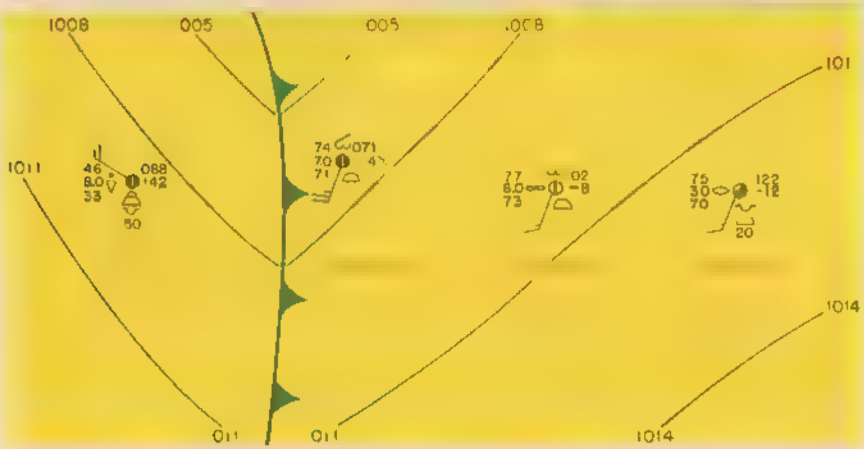


Figure 25. A "warm front": (upper) "cross section"; (lower left) as shown on a weather map; (lower right) as reported by teletype sequences.



STL E50⦶120⦶8RW- 088/46/33→↘18/979

IND 20◐E100⦶7 071/74/71↑↗24/974

CMH 15⦶100⦶6H 102/77/73↑↗12/983

PIT 15◐M20⦶3K 122/75/70↑↗12/989

Figure 26. A "cold front": (upper) "cross section"; (lower left) as shown on a weather map; (lower right) as reported by teletype sequences.

Since the general motion of the atmosphere in the United States is toward the east, the Polar and Arctic air masses generally move toward the southeast and the Tropical and Equatorial air masses move toward the northeast. The speed varies according to the season and the type of air mass, but it generally averages 500 to 700 miles a day. The cold air masses move somewhat more rapidly than the warm.

Figure 27. Weather-map indication of "wind shift line" (center line leading to "low").

When two different air masses meet they do not ordinarily mix (unless their temperatures, pressures, and relative humidities happen to be very similar). Instead they set up boundaries called frontal zones, or "fronts," with the colder air mass projecting under the warmer in the form of a wedge. This condition is termed a "stationary front" if the boundary is not moving.

Usually, however, the boundary moves along the earth's surface and, as one air mass withdraws from a given area, it is replaced by another air mass. This action creates a moving front. If warmer air is replacing colder air the front is called "warm"; if colder air is replacing warmer air, the front is called "cold."

Warm Front

When a warm front moves forward, the warm air slides up over the wedge of colder air lying ahead of it.

Warm air, usually has high humidity. As soon as warm air is lifted, its temperature is lowered, condensation occurs, and fog and drizzle begin to form. As the lifting process continues, low nimbostratus and stratus clouds form and the drizzle develops into rain. The rain falls through the colder air below, increasing its moisture content so that it also becomes saturated. Any reduction of temperature in the colder air, which might be caused by upslope motion or cooling of the ground after sunset, may result in extensive fog.

As the warm air progresses up the slope, with constantly falling temperature, clouds appear at increasing heights in the form of altostratus and cirrostratus. Finally, the air is forced up near the stratosphere and, in the freezing temperatures at that level, the condensation appears as thin wisps of cirrus clouds. The upslope movement is very gradual, rising about 1,000 feet every 20 miles. Thus, the cirrus clouds, forming at perhaps 25,000 feet altitude, may appear as far as 500 miles in advance of the point on the ground which marks the position of the front. (See fig. 25.)

Although no two fronts are exactly alike, we may perhaps gain a clearer understanding of the general pattern if we consider the atmospheric conditions which might exist when a warm front is moving eastward from St. Louis, Mo.

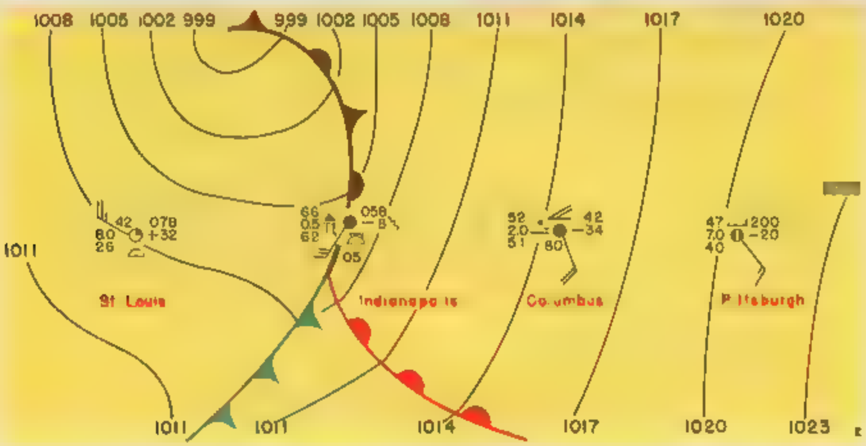
At St. Louis the weather would be very unpleasant, with drizzle, and probably fog.

At Indianapolis, Ind., 200 miles in advance of the warm front, the sky would be overcast with nimbostratus clouds, and precipitation falling in the form of continuous rain.

At Columbus, Ohio, 400 miles in advance, the sky would be broken, stratus and altostratus clouds predominating with a steady rain about to begin.

At Pittsburgh, Pa., 600 miles ahead of the front, there would probably be high cirrus and cirrostratus clouds.

If we wished to fly from Pittsburgh to St. Louis, we would experience a steady decrease in ceiling and visibility. Starting under



STL 35⊕8 078/42/26→↘23+40/976

IND E5⊕1/2TA-RW 058/66/62↗28+45/970

CMH 880⊕2R-F 142/52/51↑↖17/995/R-

PIT E130⊕7 200/47/40↖12/012

Figure 28. An "occluded front": (upper) "cross section"; (lower left) as shown on a weather map; (lower right) as reported by teletype sequences.

bright skies, with unlimited ceilings and visibilities, we would note lowering stratus-type clouds as we neared Columbus and soon afterward we would encounter precipitation. After arriving at Indianapolis, we would find the ceiling too low for further flight. Precipitation would reduce visibilities to practically zero.

Thus, we would be forced to remain in Indianapolis until the warm front had passed, which might require a day or two.

If we wished to return to Pittsburgh, we would have to wait until the front had passed beyond Pittsburgh, which might require as long as 3 or 4 days. Warm fronts generally move at the rate of from 10 to 25 miles an hour.

On our trip to Indianapolis we probably would have noticed a gradual increase in temperature and a much faster increase in dew point, until the two coincided.

We would also have found the atmospheric pressure gradually lessening because the warmer air aloft would have less weight than the colder air it was replacing. This condition illustrates the general principle that a falling barometer indicates the approach of stormy weather.

Cold Front

Let us now consider the weather conditions accompanying a cold front. When the cold front moves forward, it acts like a snow plow, sliding under the warmer air and tossing it aloft. This causes sudden cooling of the warm air, resulting in the formation of nimbostratus clouds (if the front is moving slowly) or cumulonimbus (if the front is moving rapidly) accompanied by severe precipitation with gusty and turbulent winds. (See fig. 26.)

The slope of a cold front is much steeper than that of a warm front and the progress is generally more rapid—usually from 20 to 35 miles an hour. The weather activity is more violent and usually takes place directly at the front, instead of in advance.[16] Whereas the warm front dangers lie in low ceilings and visibilities, the cold front dangers lie chiefly in sudden storms, high winds, and turbulence. Icing conditions are present in both types if the temperature is between 34° F. and 15° F.

Unlike the warm front, the cold front rushes in almost unannounced, makes a complete change in the weather within the space of a few hours, and passes on. The belt of activity, often called a "squall line," is ordinarily quite narrow—50 to 100 miles in width—but is likely to extend for hundreds of miles in length, frequently lying across the entire United States in a line running from northeast to southwest. Altostratus clouds sometimes form slightly ahead of the front, but these are seldom more than 100 miles in advance. After the front has passed, the weather clears rapidly with cooler, drier air, and usually unlimited ceilings and visibilities—almost perfect flying conditions.

If we were to make the flight from Pittsburgh toward St. Louis with a cold front approaching from St. Louis, we would experience conditions quite different from those associated with a warm front. The sky in Pittsburgh would probably be somewhat overcast with stratocumulus clouds typical of a warm air mass, the air smooth, and the ceilings and visibilities relatively low although suitable for flight.

As the flight proceeded, these conditions would prevail until we reached Indianapolis. If we were wise, we would now check the present position of the cold front by consulting a recent weather map, teletype sequences, or the meteorologist on duty. We should probably find that the front was now about 75 miles west of Indianapolis. A pilot with judgment based upon knowledge of frontal conditions would remain in Indianapolis until the front had passed—a matter of a few hours—and then continue to his destination under perfect flying conditions.

If, however, we were foolhardy enough to continue our flight toward the approaching cold front, we would soon notice a few altostratus clouds and a dark layer of nimbostratus lying low on the horizon, with perhaps cumulonimbus in the background. Two courses would now be open to us: either to turn around and outdistance the storm, or to make an immediate landing which might be extremely dangerous on account of gustiness and sudden wind shifts.

If we were to continue farther, we would be trapped in a line

[16] In the late afternoon during the warmer seasons a prefrontal line of thunderstorms will frequently develop as much as 50 to 200 miles in advance of the actual front

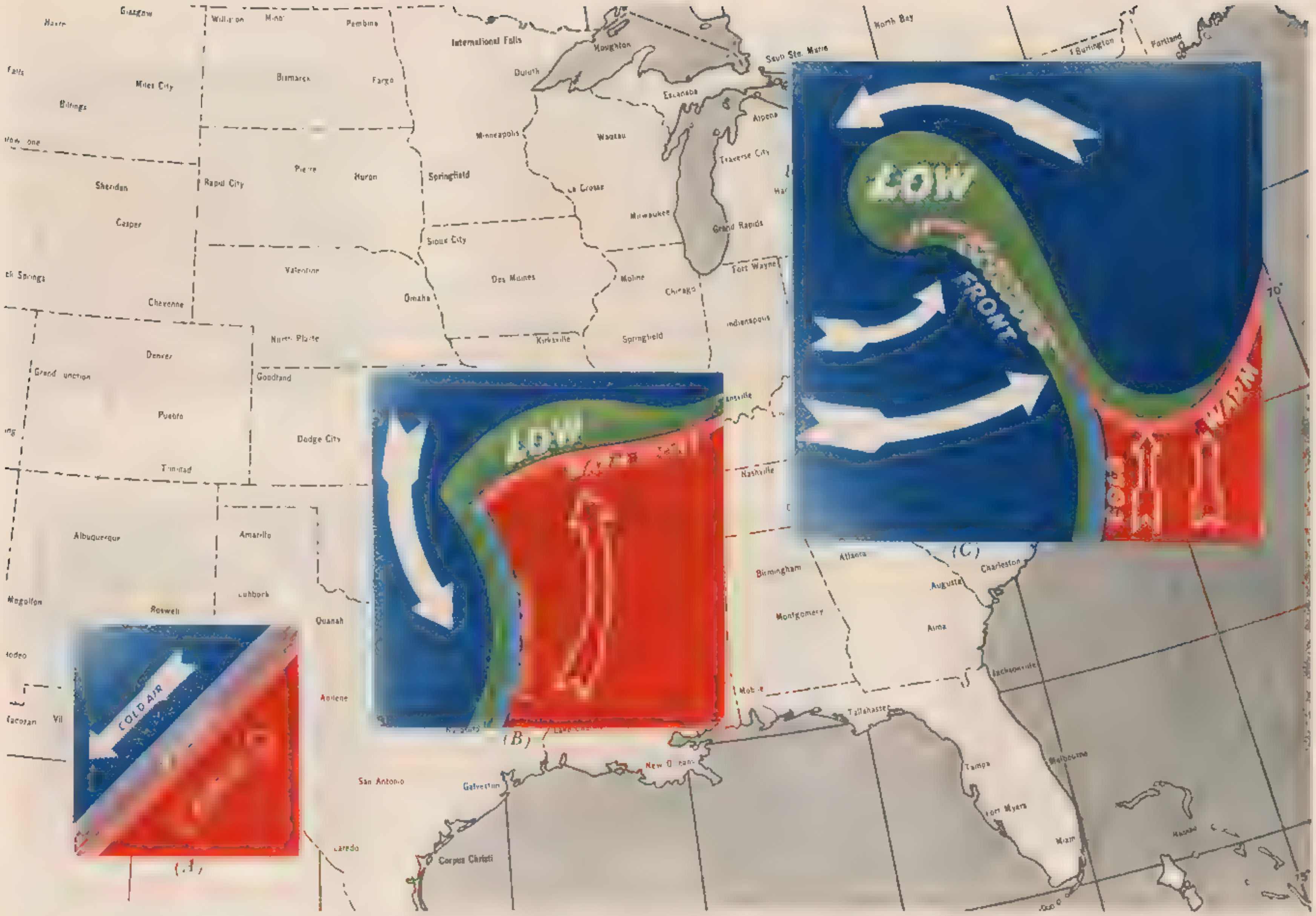


Figure 29. Three stages in the development of a typical occlusion moving northeastward

(A) Air flowing along a front in equilibrium. *(B) Increased cold-air pressure causes "bend."* *(C) Cold air begins to surround warm air.*

(D) Precipitation becomes heavier. *(E) Warm air completely surrounded.* *(F) Warm-air sector ends in mild whirl.*

Figure 30. Development of an occlusion. If warm air were red and cold air were blue, this is how various stages of an occlusion would appear to a person aloft and looking toward the earth. (Precipitation is indicated by green.)

of squalls and cumulonimbus clouds, the dangers of which have already been described. It is inviting disaster to attempt to fly beneath these clouds and impossible for a small plane to fly above them, since they frequently extend as high as 25,000 to 35,000 feet. At low altitudes there are no safe passages through them. Uusally there is no possibility of flying around them because they often extend in a line 300 to 500 miles in length.

Wind Shifts

In a previous paragraph, we mentioned "wind shifts" which perhaps requires further clarification. We remember the wind in a high blows in a clockwise spiral. When two highs are adjacent, the winds are in almost direct opposition at the point of contact as illustrated in figure 27. Since fronts always lie between two areas of higher pressure, wind shifts occur in all types of fronts, but they usually are more pronounced in cold fronts.

Occluded Front

One other form of front with which the pilot should become familiar is the "occlusion" or "occluded front." This is a condition in which an air mass is trapped between two colder air masses and forced aloft to higher and higher levels until it finally spreads out and loses its identity.

Meteorologists subdivide occlusions into two types; but so far as the pilot is concerned, the weather in any occulusion is a combination of warm-front and cold-front conditions. As the occlusion approaches, the usual warm-front indications prevail—lowering ceilings, lowering visibilities, and precipitation. Generally the warm-front weather is then followed almost immediately by the cold-front type, with squalls, turbulence, and thunderstorms.

Figure 28 is a vertical cross-section of an occlusion. Figure 29 shows the various stages as they might occur during the development of a typical occlusion. Usually the development requires 3 or 4 days, during which the air masses may progress as indicated on the map.

The first stage (a) represents a boundary between two air masses, with cold and warm air moving in opposite directions along a front. Soon, however, the cooler air, being more aggressive, thrusts a tongue under the warmer air, breaking the continuity of the boundary, as shown in (b). Once begun, the process continues rapidly to the complete occlusion as shown in (c). As the warmer air is forced aloft, it cools quickly and its moisture condenses, causing severe precipitation. The air becomes extremely turbulent, with sudden changes in pressure and temperature.

Figure 30 shows the development of the occluded front in greater detail.

Figure 31 is an enlarged view of (c) in figure 29, showing the cloud formations and the areas of precipitation.

In Figures 25, 26, and 28 a panel representing a typical weather map is placed below each cross-sectional view. These panels represent a bird's-eye view, or plan view, and show how the weather conditions are recorded. A warm front is indicated by a red line; a cold front by a blue line; an occluded front by a purple line; a stationary front by alternating red and blue dashes. The rounded and pointed projections are generally omitted from the manuscript maps, but are placed on printed or duplicated maps to distinguish the different fronts.

It should be borne in mind that the frontal lines on the weather map represent the points on the earth's surface where the fronts are located. A pilot flying west at an altitude of 5,000 feet would pass through the frontal boundary about 100 miles in advance of the point where the warm front is shown, or about 25 to 50 miles to the rear of the line on the map representing the cold front.

All the foregoing information about air masses and fronts is available to the pilot in abbreviated form on weather maps. For the pilot who understands the meaning of the symbols, a brief study of the current map will provide a fairly complete picture of the weather conditions he is likely to encounter in flight. He must realize, of course, that the map may be as much as 8 hours old, and that the fronts will have moved forward during that time. The meteorologist on duty will be able to supplement the weather map information with the latest data arriving hourly on the teletype sequences. He should invariably be consulted before flights are undertaken which involve long distances or which lie within areas in which frontal activity is taking place. Figure 32 represents a

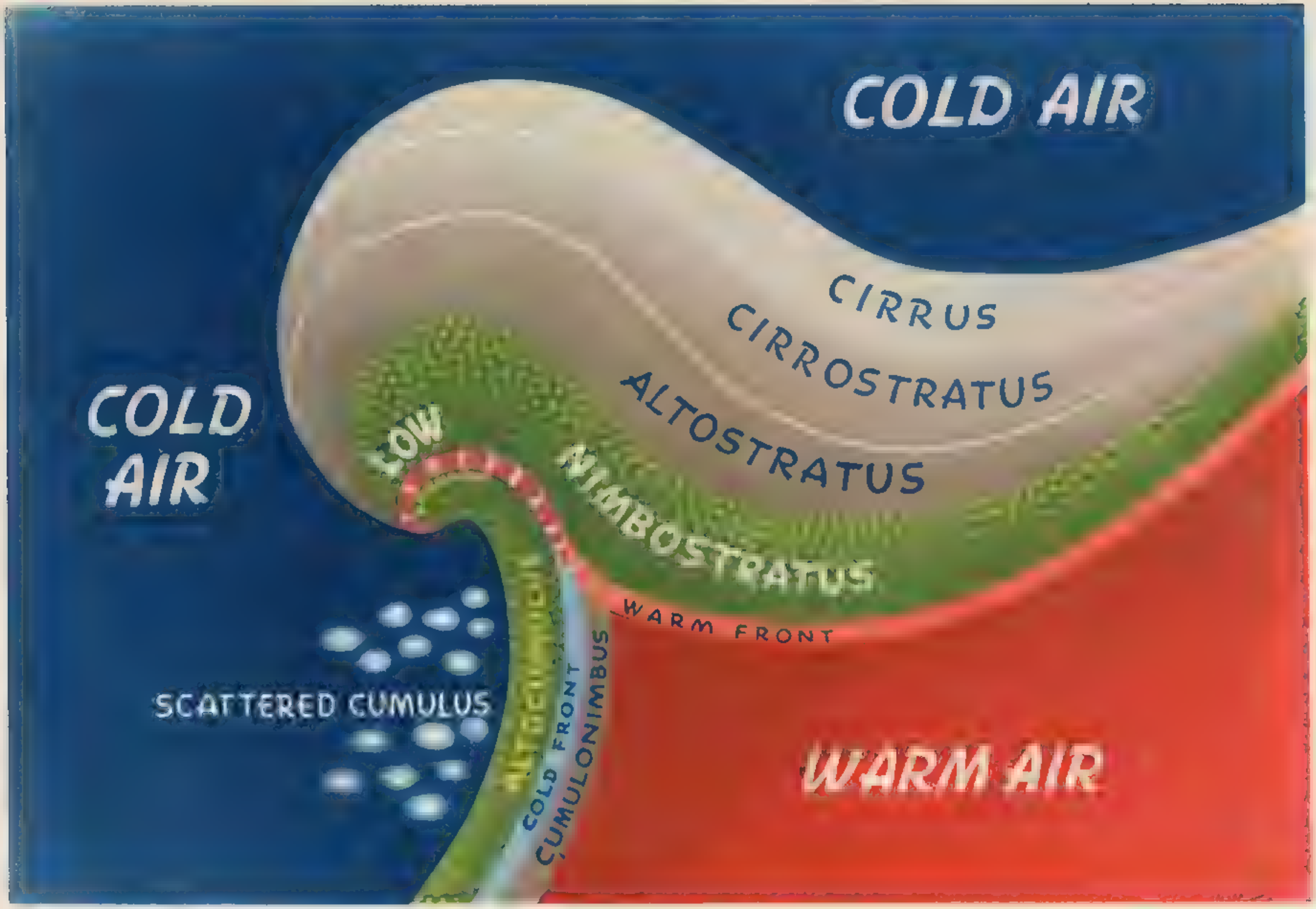


Figure 31. Cloud formations and precipitation accompanying a typical occlusion. (This presents details of the third stage of development shown in the series depicted in Figure 29.)

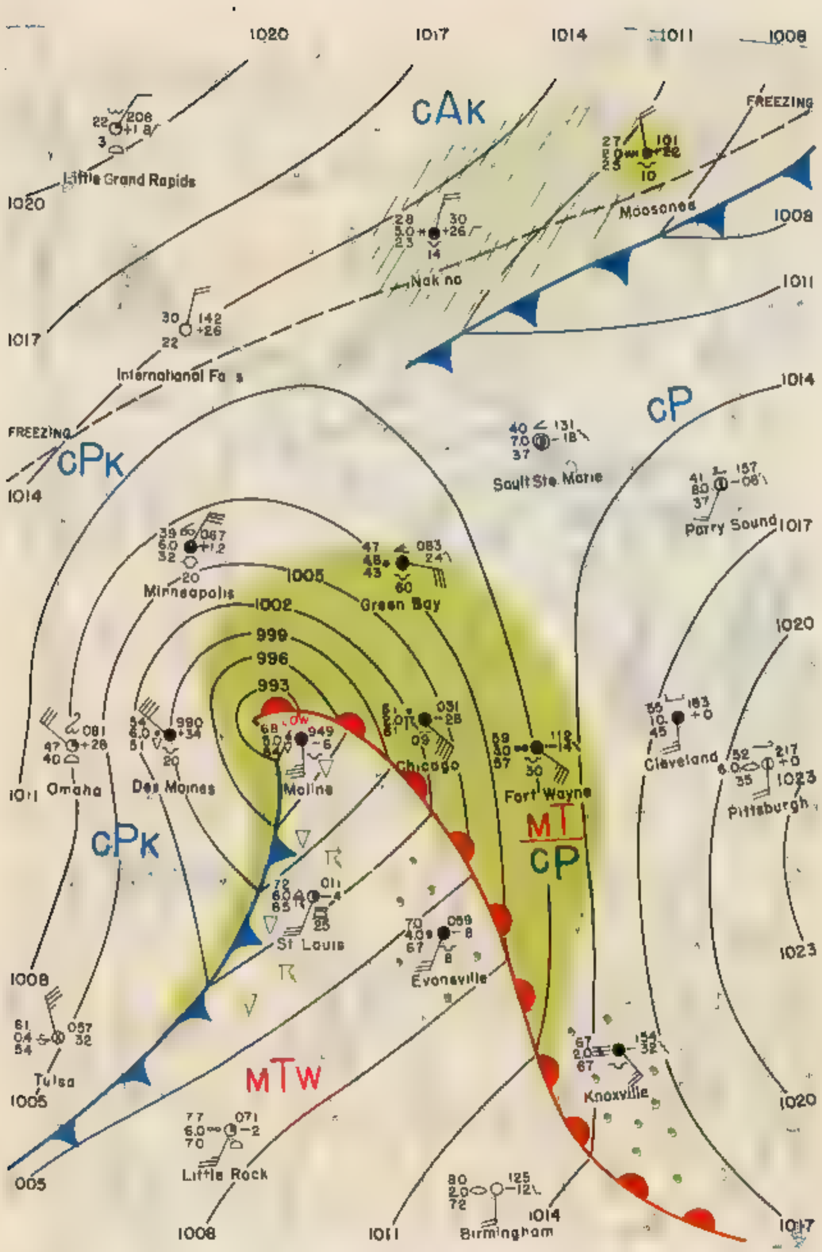


Figure 32. Section of typical weather map showing methods of indicating "weather facts" of importance to pilots.

portion of a typical weather map showing the symbols usually employed.

Sequence Reports

Changes in weather frequently are so rapid that conditions at the time of flight are likely to be quite different from those shown on a weather map issued several hours previously. The very latest information is available in the hourly teletype sequence reports transmitted by weather stations. The data are substantially the same as on the weather map, but the pilot must become familiar with a few symbols and abbreviations in order to read the sequences. Facility in reading these reports can be acquired in a surprisingly short time, and the reward is well worth the effort. Teletype reports are given below the panels in figures 25, 26, and 28.

The table on pages 40 and 41 presents a typical report, together with an explanation for interpreting all sequences. It will be noted that the information is presented in three groups, which might be broadly classified as:

1. Identification.
2. Visual Observations.
3. Instrumental Observations.

Interpretation of Weather Reports Sent by Teletype

211630E DCA 15⦶E30⊕11/2VTRW—BD 152/68/60 ↘18+30 ↑ 1618E/996/DRK NW VSBY 1V2

Symbol	Item	Interpretation	Translation
		GROUP I.—211630E DCA	
211630E	Date and time	The first two digits indicate the day of the month; the next four digits give the time (on the 24-hour clock) followed by a letter indicating the time zone. (E=Eastern; C=Central; M=Mountain; P=Pacific.) Regular sequences are sent at 30 minutes after each hour. When crucial changes occur between reporting times, a special report may be sent. In this case the date-time data will follow the station identification symbol, and the letter "S", followed by a numeral, will be added.	21st day of the month, 4:30 p. m., Eastern time.
DCA	Station identification.	Indicated by call letters. Call letters and all abbreviations are available at weather offices.	Washington, D. C.
		GROUP II.—15⦶E30⊕11/2VTRW—BD	
15⦶	Sky cover	Figures represent hundreds of feet (15=1,500 feet). Symbol indicates amount of cover: ○=clear; ⦶=scattered; ⦷=broken; ⊕=overcast. The letter "X" will be used instead of these symbols whenever fog, dust, smoke, or precipitation obscure the sky. If clouds are at varying levels, two or more sets of figures and symbols are entered in ascending order of height.	Scattered clouds at 1,500 feet.
E30⊕	Ceiling	The ceiling figure will always be preceded by one of the following letters: E=estimated; M=measured; W=indefinite; B=balloon; P=precipitation; A=reported by aircraft. If the ceiling is below 3,000 feet and is variable, the ceiling symbol will be followed by the letter "V", and in the remarks the range of height will be indicated.	Ceiling estimated 3,000 feet.
11/2V	Visibility	Figures represent miles and fractions of miles. Followed by "V" if less than 3 miles and variable. If the visibility is 6 miles or less, the reason is always given under "Precipitation" or "Obstruction."	Visibility 1½ miles, variable.
TRW-	Precipitation, thunderstorm, or tornado.	R=Rain; L=drizzLe; E=slEet; A=hAil; S=Snow; W=shoWers; T=Thunderstorm; Z=freeZing. Sometimes followed by + meaning heavy, or by — meaning light. Item omitted if there is no precipitation. Tornado is spelled out.	Thunderstorm; light rain shower.

Symbol	Item	Interpretation	Translation
BD	Obstructions to vision.	F=Fog; H=Haze; D=Dust; N=saNd; K=smoKe (sometimes the above letters are preceded by G=ground; I=ice; B=blowing).	Blowing dust.
		GROUP III.—152/68/60→↘18+30↑1618E/996/DRK NW VSBY 1V2	
		Most of the items in this group are separated by diagonal lines (/).	
152/	Pressure	Stated in millibars using same system as on the weather map (omitting initial "9" or "10").	Pressure 1015.2 millibars.
68/	Temperature	In degrees Fahrenheit	Temperature 68° F.
60	Dew point	In degrees Fahrenheit	Dew point 60° F.
→↘18+30 ↑1618E/	Wind	Wind direction is shown by arrows, either singly or in combination: ↓=North; ↓↙=North-northeast; ↙=Northeast; ←↙=East-northeast; ←=East, etc. Wind speed is indicated by figures indicating m. p. h. (C for calm.) If followed by + = gusts; figures following the + indicate intensity of the gust peaks. If a wind shift has occurred at the station, it is indicated by an additional arrow, followed by figures showing time of shift.	Wind West-northwest, 18 m. p. h.; gusts to 30 m. p. h.; wind shift from south at 4:18 p. m., Eastern time.
996/	Altimeter setting	Barometric pressure in inches for the setting of altimeters on aircraft. Given in three figures with the initial 2 or 3 omitted. A number beginning with 5 or higher presupposes an initial 2; a number beginning with 4 or lower presupposes an initial 3. (993=29.93; 102=31.02, etc.).	Altimeter setting at 29.96 inches.
DRK NW VSBY 1V2	Remarks	Any additional remarks are given in teletype symbols and in abbreviations of English words. Any items which are normally sent, but for some reason are missing from the transmission, are represented by the letter "M."	Dark overcast to the Northwest. Visibility variable 1 to 2 miles.

☆ U. S. GOVERNMENT PRINTING OFFICE : O—1951—947285

Slope of a cold Front = 1-40 to 1-80 or

in 80 miles of the ground means

the slope is up 1 mile

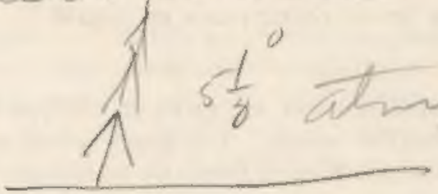
Slope of a warm Front is from 1-80 to 1-200

Temp − Dew Point ÷ 4.5 = the base of the Cumulus clouds in 1000 of Feet

Page 83.

2°3°

cumulus stat



$5\frac{1}{8}°$ atmosphere

P 26 27, (30.)

Chapter 8 - p 84

12 answers #9.

T 85

1 5

85

25

5.

4

PREPARED BY
CAA AVIATION INFORMATION

.555

45) 25.000
22.5
2.50
2.25
.250
.225
.25